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# Evaluation of the CEAS Trend and Monthly Weather Data Models for Spring Wheat Yields in North Dakota and Minnesota

Jeanne L. Sebaugh

EVALUATION OF THE CEAS TREND AND MONTHLY WEATHER DATA MODELS FOR SPRING WHEAT YIELDS IN NORTH DAKOTA AND MINNESOTA. By Jeanne L. Sebaugh; Research Division, Statistical Reporting Service, U. S. Department of Agriculture, Columbia, Missouri 65201; December 1981. SRS Staff Report No. AGES 811214

## ABSTRACT

The CEAS models evaluated use the basic input variables of year and monthly average temperature and total precipitation to forecast and estimate spring wheat yields in North Dakota and Minnesota. Historic trend, meteorological and agroclimatic variables are constructed. Stepwise multiple regression techniques are used to develop state and crop reporting district regression models based on historic values of these variables and yield. Evaluation of yield reliability at the state level indicates that the bias is less than one quintals/hectare. The Minnesota model is somewhat less reliable than the North Dakota model. The models are objective and adequate (in terms of coverage) for short-term use in North Dakota and Minnesota. Consistency with scientific knowledge could be more thoroughly documented. Timely yield forecasts and estimates can be made during the growing season using estimates of climatic division weather data. The models are not costly to operate but the costs of future updates should be considered. Users can easily understand the form of the models and how to use them. The model standard errors of prediction do not provide a useful current measure of modeled yield reliability.

Key Words: Model evaluation, crop yield modeling, regression models, spring wheat yield models.



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# EVALUATION OF THE CEAS TREND AND MONTHLY WEATHER DATA MODELS FOR SPRING WHEAT YIELDS IN NORTH DAKOTA AND MINNESOTA

by
Jeanne L. Sebaugh
Mathematical Statistician

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AgRISTARS
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## SUMMARY AND CONCLUSIONS

The CEAS models evaluated were developed to forecast and estimate spring wheat yields in North Dakota and Minnesota. Historic trend, meteorological and agroclimatic variables were constructed from the basic input variables of year and monthly average temperature and total precipitation. Separate models were developed for eleven CRDs and two states using stepwise multiple regression procedures. Bootstrap testing on the end-of-season models has been performed to obtain indicators of yield reliability and current measures of modeled yield reliability.

Indicators of yield reliability show that accurate estimates are more difficult to make in four of the CRDs than in the other seven. At the state level, the indicated bias is generally less than one quintal/hectare and the standard deviation is between one and two quintals/hectare. The models are objective and adequate (in terms of coverage) for short-term use in North Dakota and Minnesota. Although the basic approach used by the model developer is not inconsistent with scientific knowledge, the relationship of the specific results obtained to known scientific theories could have been discussed in greater detail. Timely yield forecasts and estimates can be made during the growing season by using weather data approximating climatic division values. The models are not costly to operate, but the costs of updating the models in future years should be considered. Users can easily understand the form of the models and how to use them. The model standard errors of prediction do not provide a useful current measure of modeled yield reliability.

## DESCRIPTION OF THE MODELS

These spring wheat models were developed by the Climatic and Environmental Assessment Services (CEAS) (LeDuc, 1981) to predict Crop Reporting District (CRD) and state yields in North Dakota and Minnesota. (CEAS is a part of the National Oceanic and Atmospheric Administration (NOAA) within the U.S. Department of Commerce.)

Statistical regression techniques and historic data were used for model development. The basic historic variables are year, yield (durum plus other spring wheat), and monthly average temperature (T) and total precipitation (P). A number of weather-related variables are derived from the monthly temperature and precipitation. Trend (as a function of year) and weather-related terms are selected for inclusion in the models by a stepwise regression procedure. The variables included in each CRD and state model are shown in the Appendix.

Several meteorological variables are derived in a straightforward manner. For example, precipitation is accumulated over selected months. Also, the deviation of a month's average temperature, total precipitation or several months' accumulated precipitation from the variables long term average is computed.

The "deviations from normal" (DFN) are considered for inclusion in the models as both linear and quadratic terms. Temperature DFN is only selected as a linear term. Temperature DFN is included in the North Dakota (ND) CRD 40 model for May, in all of the North Dakota models except CRD 10 for June, and in all of the models for North Dakota and Minnesota (MN) except ND CRD 10 and 80 for July (Appendix). Precipitation DFN is also only selected as a linear term. Precipitation DFN is included in the ND CRD 10 model for July and in ND CRD 50 for August. Cumulative precipitation from September through April is included in ND CRD 10 model, from September through May in ND models for CRD 70 and 80, and from October through March in the MN state model. Cumulative precipitation from September is included as a squared DFN term in the MN CRD 10 model as accumulated through June, and in models for ND CRD 20 and 30 and MN CRD 40 as accumulated through August.

Other weather-related variables which were felt to better represent the impact of moisture and heat stress are also calculated. Moisture is supplied by water stored in the soil and is replenished by rainfall. Moisture is lost from the available water capacity of the soil directly through evaporation and indirectly through transpiration from the plants. Actual evapotranspiration (ET) is defined as the actual water loss by transpiration from the leaves and by evaporation from the underlying surface. Potential evapotranspiration (PET) is defined as the maximum possible ET which would occur if soil moisture over a large area were not a limiting factor. An approximation to the monthly PET is calculated using a procedure developed by Thornthwaite (1948). The calculations require the current and "normal" monthly temperature and the latitude of the geographic location. ET can then be calculated as a function of PET, monthly precipitation, and the contents and capacity of a soil moisture budget. The soil moisture budget is maintained according to Palmer (1965). Evapotranspiration which is considered to be "climatically appropriate for existing conditions" (CAFEC) is computed as $\alpha$PET, where $\alpha = \overline{ET}/\overline{PET}$ and $\overline{ET}$ and $\overline{PET}$ are long term averages for a particular month. This quantity indicates the value ET would have to have in order to be in its historic ratio to PET.

Three quantities are calculated from these moisture stress variables for possible inclusion in the spring wheat models. They are: (1) the ratio of ET to the climatically appropriate ET (ET/CAFEC(ET)), (2) the difference between total precipitation and PET (P-PET), and (3) the ratio of total precipitation to PET (P/PET). PET can be thought of as indicating the plant's demand for moisture and ET or P can be thought of as indicating the supply of moisture. Therefore, quantities (2) and (3) are comparisons of supply with demand. Moisture stress is indicated if (2) is more negative or if (3) is closer to zero. The CAFEC(ET) in quantity (1) represents what ET should be this month if it is to have its "normal" relationship to PET. Values of the ratio, ET/CAFEC(ET), closer to zero again reflect moisture stress. Quantity (1) is proportional to another quantity which is often used to reflect stress, the R-index (Yao, 1974). R is defined as the ratio of ET to PET and would perform the same function in a regression equation as quantity (1) which is the ratio of ET to $\alpha$PET.

These three quantities are considered for inclusion in the models as linear variables. Quantity (1) appears in the North Dakota CRD 40 model for May, in the models for ND CRD 50, 80 and the state model for June, and in the ND CRD 90 model for August. Quantity (2) for May and June appears in the ND CRD 10 model. Quantity (3) appears in the Minnesota state model for May, in the ND CRD 70 model for June, in the ND CRD 10 model for July, and in ND CRD 50 for August.

Linear functions of the year number are used as surrogates for technology in all models. The single trend term for all of the Minnesota models allows a linear increase in yield between 1955 and 1978. Contributions to yield from technology are considered nil prior to 1955 and after 1978. Three trend terms are considered for possible inclusion in the North Dakota models. One allows a linear increase in yield between 1955 and 1966, the next a linear increase between 1966 and 1973, and the last a linear increase from 1973 on. The first trend term, between 1955 and 1966, is included in all of the North Dakota models. The second term, between 1966 and 1973, is included only in the model for ND CRD 90. The third trend term is not included in any model. The contribution to yield from technology is considered nil for any time period not covered by an included trend term.

To be included in any model, a meteorological or agroclimatic variable has to meet several requirements. First, the variable either has to be linearly correlated with de-trended yield or has to be "felt" (LeDuc, 1981) to be physically significant. Secondly, the variable has to be selected by a stepwise regression routine using least squares estimation and a combination of forward selection and backward elimination. Finally, a selected variable has to have a "correct" (LeDuc, 1981) sign.

The weather variables for the state models, including the derived variables, are weighted averages of the variables as calculated for each CRD in the state. The weight used is harvested area, although planted area is suggested for prediction purposes. Models were independently developed for each CRD (10-90 in ND and 10 and 40 in MN) and the state using the previously described procedures. Weather and yield data from 1931 to 1978 were used to develop the North Dakota models and data from 1936 to 1978 were used to develop the Minnesota models. Exclusion or modification of any yields because of the known occurrence of episodic events, such as hail or disease damage, is not mentioned.

## EVALUATION METHODOLOGY

### Eight Model Characteristics to be Discussed

The document, Crop Yield Model Test and Evaluation Criteria, (Wilson, et. al., 1980), states:

> "The model characteristics to be emphasized in the evaluation process are: yield indication reliability, objectivity, consistence with scientific knowledge, adequacy, timeliness, minimum costs, simplicity, and accurate current measure of modeled yield reliability."

Each of these characteristics will be discussed with respect to the CEAS trend and monthly weather data spring wheat yield models.

### Bootstrap Technique Used to Generate Indicators of Yield Reliability for the End-of-Season Models

Indicators of yield reliability (reviewed below) require that the parameters of the regression model be computed for a set of data and that a yield prediction be made based on that data for a given "test" year. The values required to generate indicators of yield reliability include the predicted yield, $\hat{Y}$, the actual (reported) yield, Y, and the difference between them, $d = \hat{Y}-Y$, for each test year. It is desirable that the data used to generate the parameters for the model not include data from the test year.

To accomplish this, the "bootstrap" technique is used. Years from an earlier base period are used to fit the model and obtain a prediction equation. The values of the independent variables for the test year following the base period are inserted into the equation and a predicted yield is generated. Then, that test year is added to the base period and the process is repeated for the next sequential test year. Continuing in this way, ten (1970-1979) predictions of yield are obtained, each independent of the data used to fit the model. For North Dakota, data for 1931-1969 (39 years) are used to fit prediction models for 1970, date for 1931-1970 (40 years) are used to fit prediction models for 1971, etc. For Minnesota, data for 1936-1969 are used to fit prediction models for 1970 (34 years), data for 1936-1970 are used to fit prediction models for 1971 (35 years), etc.

Even though the data used to estimate the regression coefficients do not include the test year, this procedure does not result in a predicted yield which is totally independent of the data from the test year. The model developer used data through 1978 (which includes nine of the test years) to select the variables which are included in each model and to determine the break points for trend. It is unrealistic to require the model developer to develop ten models for each CRD and state which truly use only data up to but not including each test year. Since the procedures used for variable selection and break point determination include subjective decisions, the process cannot be simulated accurately by the model evaluator. Therefore, the bootstrap procedure described neither tests how well these models can perform in the future nor how well the model developer can incorporate future changes in trend.

The average production and yield over the ten year test period are listed in Table 1 for each geographic area. Also shown is the percent production each CRD contributes to its state and the two state region and the percent production each state contributes to the region. The percentage of regional production for each CRD is shown graphically in Figure 1. Darker shades indicate higher average productivity.

Separate models are derived for each CRD in North Dakota, for CRDs 10 and 40 in Minnesota, and for each state. Predicted yields at the state level are also obtained by using a weighted average of that state's CRD predicted yields. The state model for Minnesota is based on yields and weather aggregated from all nine CRDs while the results aggregated from CRDs are only from CRDs 10 and 40. Over eighty-five percent of Minnesota spring wheat is produced in those two CRDs (Table 1). Predicted yields for the region are also obtained using a weighted average of the values from the CRD models and from the state models. The weighting factor used is harvested area. Results obtained by aggregating from the CRD models are identified as "CRDs aggr." Results obtained by aggregating from the state models are identified as "state aggr." Although models have been developed for use before and during the growing season, they are not included in this discussion and only the reliability of the end-of-season models is examined here.

## Review of Indicators of Yield Reliability

The Y, $\hat{Y}$ and d values for the ten-year test period at each geographic area may be summarized into various indicators of yield reliability.

### Indicators Based on the Differences Between $\hat{Y}$ and Y ($d = \hat{Y}-Y$) Demonstrate Accuracy, Precision and Bias

From the d value, the mean square error (root and relative root mean square error), the variance (standard deviation and relative standard deviation), and the bias (its square and the relative bias) are obtained.

The root mean square error (RMSE) and the standard deviation (SD) indicate the accuracy and precision of the model and are expressed in the original units of measure (quintals/hectare). Assuming the d values are normally distributed, it is about 68% probable that the absolute value of d for a future year will be less than one RMSE and 95% probable that it will be less than twice the RMSE. So, accurate prediction capability is indicated by a small RMSE.

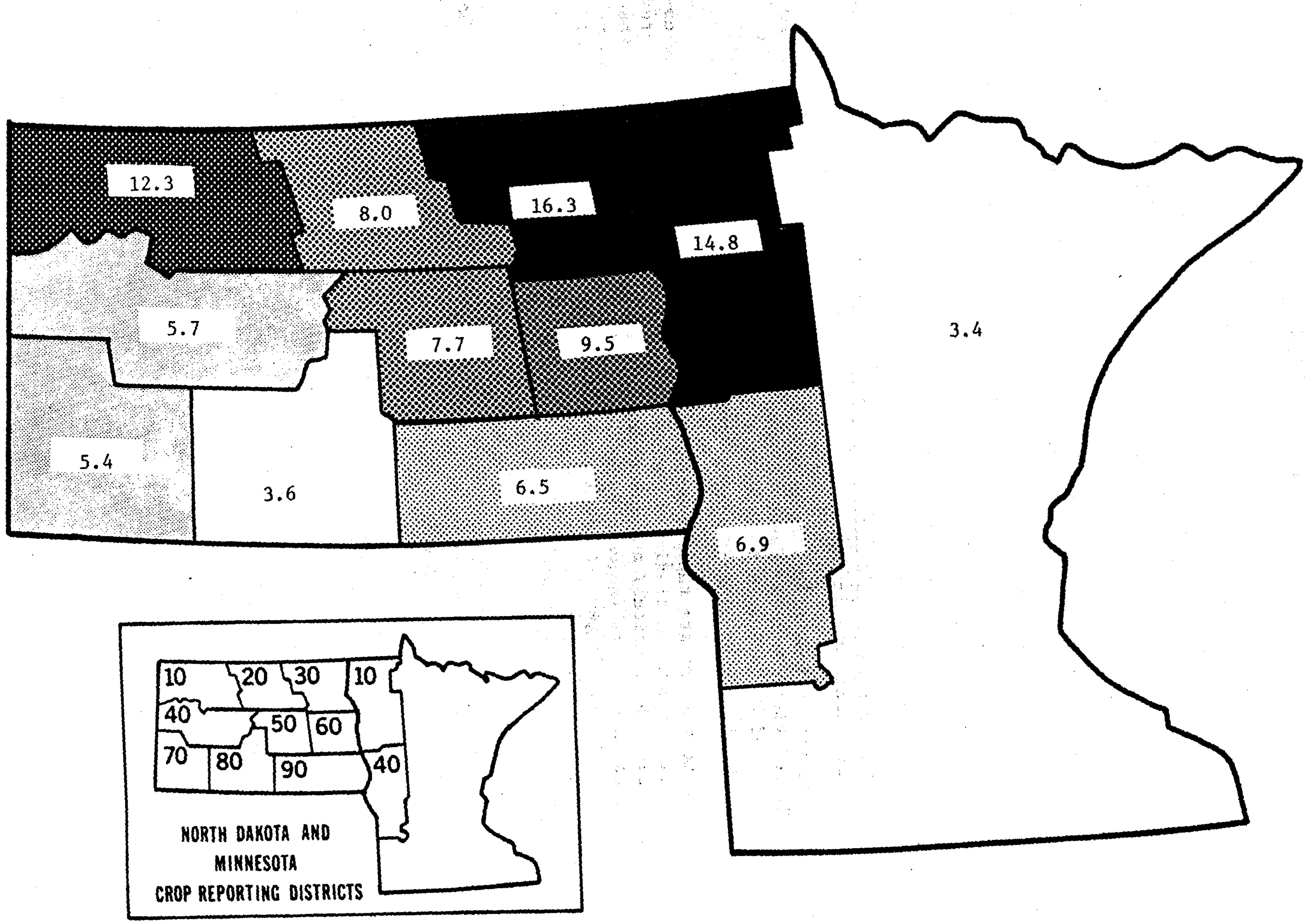
A non-zero bias means the model is, on the average, overestimating the yield (positive bias) or underestimating the yield (negative bias). The SD is smaller than the RMSE when there is non-zero bias and indicates what the RMSE would be if there were no bias. If the bias is near zero, the SD and the RMSE will be close in value. We prefer a model whose bias is close to zero.

TABLE 1
AVERAGE PRODUCTION AND YIELD
FOR TEST YEARS 1970-79

SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

| STATE | CRD | PRODUCTION (1,000) QUINTALS | PRODUCTION (1,000) BUSHELS | PERCENT OF STATE | PERCENT OF REGION | YIELD QNTL/HA | YIELD BU/ACRE |
|---|---|---|---|---|---|---|---|
| N.DAKOTA | 10 | 10,803 | 39,693 | 16.5 | 12.3 | 17.8 | 26.5 |
| | 20 | 6,985 | 25,664 | 10.6 | 8.0 | 17.1 | 25.5 |
| | 30 | 14,255 | 52,378 | 21.7 | 16.3 | 20.7 | 30.8 |
| | 40 | 4,965 | 18,242 | 7.6 | 5.7 | 16.7 | 24.8 |
| | 50 | 6,769 | 24,873 | 10.3 | 7.7 | 16.7 | 24.8 |
| | 60 | 8,280 | 30,422 | 12.6 | 9.5 | 20.3 | 30.3 |
| | 70 | 4,756 | 17,474 | 7.2 | 5.4 | 16.4 | 24.3 |
| | 80 | 3,123 | 11,473 | 4.8 | 3.6 | 13.1 | 19.5 |
| | 90 | 5,676 | 20,855 | 8.7 | 6.5 | 16.1 | 23.9 |
| STATE | | 65,611 | 241,075 | | 74.9 | 17.7 | 26.4 |
| MINNESOTA | 10 | 12,984 | 47,707 | 59.0 | 14.8 | 23.7 | 35.2 |
| | 20 | 131 | 480 | 0.6 | 0.1 | 19.4 | 28.8 |
| | 30 | 4 | 14 | 0.0 | 0.0 | 17.9 | 26.6 |
| | 40 | 6,025 | 22,136 | 27.4 | 6.9 | 20.6 | 30.6 |
| | 50 | 1,231 | 4,523 | 5.6 | 1.4 | 22.7 | 33.7 |
| | 60 | 43 | 158 | 0.2 | 0.0 | 20.0 | 29.7 |
| | 70 | 660 | 2,424 | 3.0 | 0.8 | 21.9 | 32.6 |
| | 80 | 664 | 2,441 | 3.0 | 0.8 | 24.2 | 35.9 |
| | 90 | 255 | 936 | 1.2 | 0.3 | 22.0 | 32.7 |
| STATE | | 21,996 | 80,820 | | 25.1 | 22.8 | 33.9 |
| REGION | | 87,607 | 321,894 | | | 18.8 | 27.9 |

Figure 1. Production of spring wheat by CRD (1970-79 average) as a percent of the regional total. Darker shades indicate CRDs with higher production.



## Indicators Based on Relative Differences Between $\hat{Y}$ and Y (rd = 100d/Y) Demonstrate Worst and Best Performance

The relative difference, rd, is an especially useful indicator in years where a low actual yield is not predicted accurately. This is because years with small observed actual yields and large differences often have the largest rd values.

Several indicators are derived using relative differences. In order to calculate the proportion of years beyond a critical error limit, we count the number of years in which the absolute value of the relative difference exceeds the critical limit of 10 percent. Values between 5 and 25 percent were investigated and a critical limit of 10 percent was found most useful in describing model performance. The worst and next to worst performance during the test period are defined as the largest and next to largest absolute value of the relative difference. The range of yield indication accuracy is defined by the largest and smallest absolute values of the relative difference.

## Indicators Based on $\hat{Y}$ and Y Demonstrate Correspondence Between Actual and Predicted Yields

Another set of indicators demonstrates the correspondence between actual and predicted yields. It is desirable for increases in actual yield to be accompanied by increases in predicted yields. It is also desirable for large (small) actual yields to correspond to large (small) predicted yields.

Two indicators relate the change in direction of actual yields to the corresponding change in predicted yields. One looks at change from the previous year (nine observations) and the other at change from the average of the previous three years (seven observations). A base period of three years is used since a longer base period would further decrease the number of observations, while a shorter period would not be very different from the comparison to a single previous year.

Finally, the Pearson correlation coefficient, r, between the set of actual and predicted values for the test years is computed. It is desirable that $r(-1 \leq r \leq +1)$ be large and positive. A negative r indicates smaller predicted yields occurring with larger observed yields (and vice versa).

## Current Measure of Modeled Yield Reliability Defined By a Correlation Coefficient

One of the model characteristics to be evaluated is its ability to provide an accurate, current measure of modeled yield reliability. Although a specific statistic was not discussed in the paper, Crop Yield Model Test and Evaluation Criteria, (Wilson, *et al*., 1980), it was stated that:

> "This 'reliability of the reliability' characteristic can be evaluated by comparing model generated reliability measures with subsequently determined deviation between modeled and 'true' yield."

For regression models, this suggests the use of a correlation coefficient between two variables generated for each test year. One variable is an indicator of the precision with which a prediction for the next year can be made, based on the model development base period. The other variable (obtained retrospectively) is an indicator of how close the predicted value for the next year actually is to the "true" value. The estimate of the standard error of a predicted value from the base period model, $s_{\hat{Y}}$, is often used for the first value, and the absolute value of the difference between the predicted and actual yield in the test year is used as the second variable, $|d|$.

A non-parametric (Spearman) correlation coefficient, r, is employed since the assumption of bivariate normality cannot be made. A positive value of $r(-1 \leq r \leq +1)$ indicates agreement between $s_{\hat{Y}}$ and $|d|$, i.e., a smaller (larger) value of $s_{\hat{Y}}$ is associated with a smaller (larger) value of $|d|$. An r value close to +1 is desirable since it indicates that a small standard error of prediction (and therefore a narrow prediction interval about the yield being predicted) is associated with small discrepancies between predicted and actual yields. If this were the case, one would have confidence in $s_{\hat{Y}}$ as an indicator of the accuracy of $\hat{Y}$.

A model related reliability measure other than $s_{\hat{Y}}$ could be suggested for use. In the present case, the model developer did not recommend any measure, so $s_{\hat{Y}}$ is used.

## MODEL EVALUATION

### Indicators of Yield Reliability Based on $d = \hat{Y} - Y$ Show Bias Usually Less Than 1 Quintal/Hectare and Standard Deviation Between 1 and 4 Quintals/Hectare

The CRD, state, and region values of indicators of yield reliability based on d are given in Table 2. The bias is generally less than a quintal/hectare except for CRD 80 in North Dakota and CRD 40 in Minnesota. Other than for those two CRDs and CRD 90 in North Dakota, the relative bias is less than five percent. The root mean square error is between one and three quintals/hectare except for CRD 40 in Minnesota which has a value of 4.18 quintals/hectare (Figure 2). The relative root mean square error is over twenty percent in North Dakota CRD 80 and Minnesota CRD 40. It is between ten and twenty percent in four CRDs in North Dakota, but less than ten percent elsewhere. The values for the standard deviation and relative standard deviation are comparable to those for the root mean square error, reflecting the minimal impact of bias.

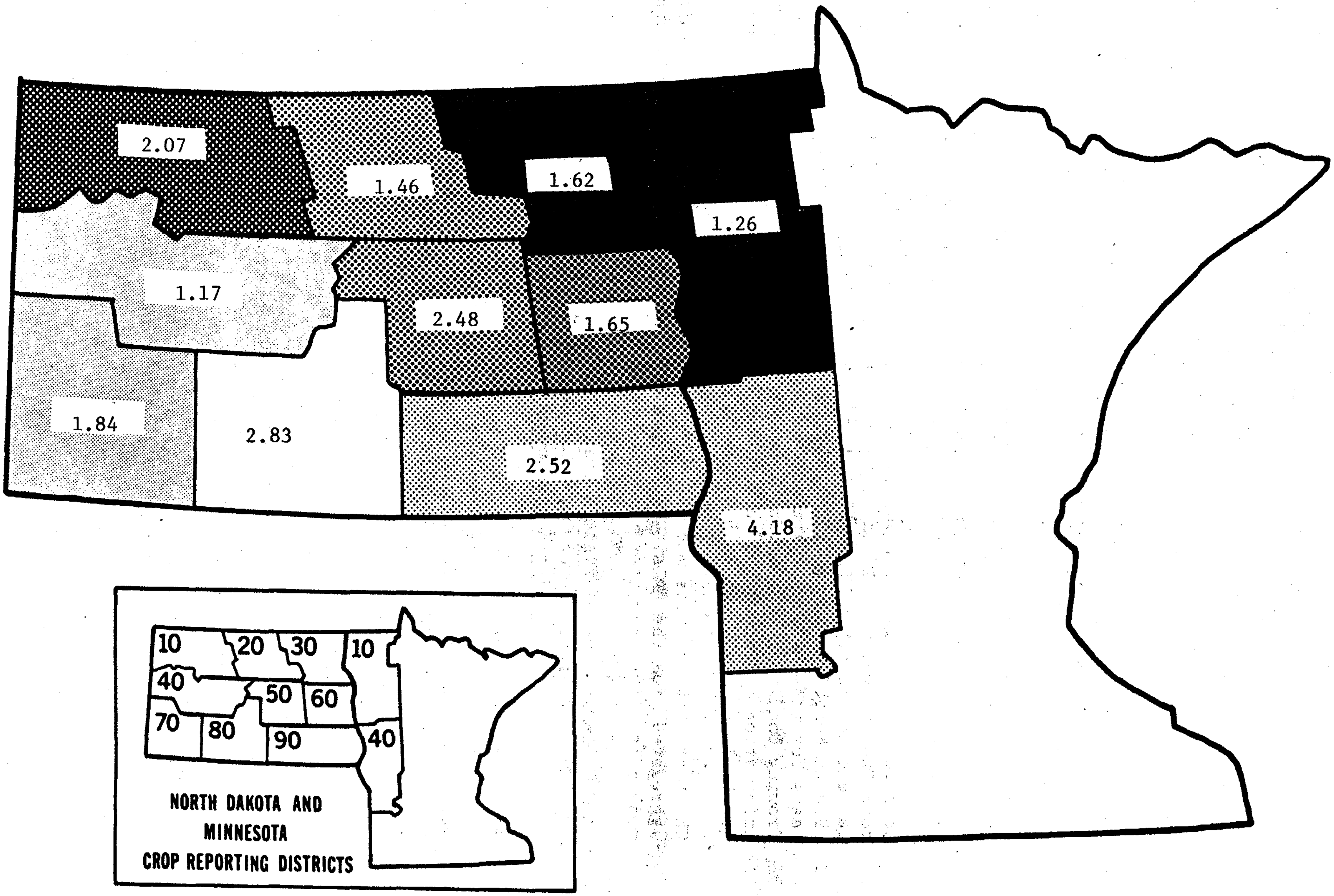
TABLE 2
INDICATORS OF YIELD RELIABILITY
BASED ON D = PREDICTED - ACTUAL YIELD

CEAS MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

MSE, VAR, B-SQR (QUINTALS/HECTARE SQUARED)
RMSE, SD, BIAS (QUINTALS/HECTARE)
RRMSE, RSD, RB (PERCENT OF AVERAGE YIELD)

| STATE | CRD | MSE | RMSE | RRMSE | VAR | SD | RSD | B-SQR | BIAS | RB |
|---|---|---|---|---|---|---|---|---|---|---|
| N.DAKOTA | 10 | 4.30 | 2.07 | 11.6 | 4.26 | 2.06 | 11.4 | 0.04 | 0.21 | 1.2 |
| | 20 | 2.13 | 1.46 | 8.5 | 1.87 | 1.37 | 7.8 | 0.26 | 0.51 | 3.0 |
| | 30 | 2.61 | 1.62 | 7.8 | 2.60 | 1.61 | 7.8 | 0.01 | -0.11 | -0.5 |
| | 40 | 1.36 | 1.17 | 7.0 | 1.28 | 1.13 | 6.9 | 0.08 | -0.28 | -1.7 |
| | 50 | 6.15 | 2.48 | 14.9 | 5.54 | 2.35 | 14.8 | 0.61 | -0.78 | -4.7 |
| | 60 | 2.72 | 1.65 | 8.1 | 2.43 | 1.56 | 7.9 | 0.28 | -0.53 | -2.6 |
| | 70 | 3.40 | 1.84 | 11.3 | 2.99 | 1.73 | 11.0 | 0.41 | -0.64 | -3.9 |
| | 80 | 7.99 | 2.83 | 21.6 | 6.86 | 2.62 | 18.5 | 1.12 | 1.06 | 8.1 |
| | 90 | 6.33 | 2.52 | 15.6 | 5.48 | 2.34 | 13.8 | 0.85 | 0.92 | 5.7 |
| STATE MODEL | | 1.60 | 1.26 | 7.1 | 1.26 | 1.12 | 6.6 | 0.34 | -0.58 | -3.3 |
| CRDS AGGR. | | 1.53 | 1.24 | 7.0 | 1.53 | 1.24 | 7.0 | 0.00 | 0.04 | 0.2 |
| MINNESOTA | 10 | 1.58 | 1.26 | 5.3 | 1.04 | 1.02 | 4.2 | 0.53 | 0.73 | 3.1 |
| | 40 | 17.49 | 4.18 | 20.3 | 14.67 | 3.83 | 17.2 | 2.82 | 1.68 | 8.2 |
| STATE MODEL | | 3.46 | 1.86 | 8.2 | 3.11 | 1.76 | 7.5 | 0.35 | 0.59 | 2.6 |
| CRDS AGGR. | | 4.38 | 2.09 | 9.3 | 3.26 | 1.81 | 7.6 | 1.12 | 1.06 | 4.7 |
| REGION | | | | | | | | | | |
| CRDS AGGR. | | 1.49 | 1.22 | 6.5 | 1.44 | 1.20 | 6.3 | 0.05 | 0.23 | 1.2 |
| STATES AGGR. | | 1.28 | 1.13 | 6.0 | 1.16 | 1.08 | 5.8 | 0.12 | -0.35 | -1.9 |

Figure 2. Root mean square error (RMSE) for CEAS spring wheat model in quintals per hectare based on test years 1970-1979. Darker shades indicate CRDs with higher production.



In North Dakota, the root mean square errors and standard deviations at the state level are smaller than for all of the CRDs except one. In Minnesota, the values are smaller at the state level than they were for CRD 40 but larger than they were for CRD 10. At the state level, there is not a consistent difference between results from the state model and the CRDs aggregated. The method of aggregation to the region level does not make a significant difference in the results based on d.

## Indicators of Yield Reliability Based on rd = 100d/Y Show 10-80 Percent of the Years Have rd Greater Than 10 Percent and Largest rd Between 10 and 70 Percent

The CRD, state, and region values for indicators of yield reliability based on rd are given in Table 3. CRD values are also shown in Figures 3-5. CRDs 50, 80 and 90 in North Dakota and 40 in Minnesota again exhibit the worst performance. The percent of years for which the absolute value of the relative difference is greater than 10% ranges between 50 and 80 percent for those four CRDs. The results for the other CRDs are between 10 and 30 percent. The largest absolute value of the relative difference for those four CRDs ranged from 25 to 69 percent. The results are between 11 and 23 percent in the other CRDs. The year with the largest $|rd|$ tended to be 1974 in North Dakota and 1978 in Minnesota. These were both low yielding years for those states. The section of the Appendix, Brief Description of Growing Conditions for Spring Wheat in Bootstrap Test Years, provides information on individual test years. The smallest $|rd|$ is sometimes zero (2 CRDs) but ranged up to 5 percent in North Dakota CRD 50.

The North Dakota state model performs slightly better than state results aggregated from the CRDs. The regional results aggregated from the state models is slightly better than the results aggregated from the CRDs.

## Indicators of Yield Reliability Based on $\hat{Y}$ and Y Show Correspondence Between the Direction of Change in Predicted as Compared to Actual Yields

Plots of the actual and predicted yields over the ten-year test period using the state level models are displayed in Figures 6 and 7. The CRD, state, and region values for indicators of yield reliability based directly on actual and predicted yields are given in Table 4. CRD values are also shown in Figures 8-10.

In all models, the change in direction of predicted yields agrees with the change in direction of actual yields both from the previous year and from the average of the three previous years over fifty percent of the time. The Pearson correlation coefficient between actual and predicted yields is significantly larger than zero and positive for all but three of the CRD models (ND CRDs 80 and 90, and MN CRD 40).

Although these indicators of yield reliability indicate a correspondence between the direction of change in predicted as compared to actual yields, one can see from Figures 6 and 7 that for the state models the predicted yields do not take on the extreme values of the actual yields. For example,

TABLE 3
INDICATORS OF YIELD RELIABILITY
BASED ON RD = 100 * ((PREDICTED-ACTUAL YIELD)/ACTUAL YIELD)

CEAS MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

| STATE | CRD | PERCENT OF YEARS \|RD\|>10% | LARGEST \|RD\| RD (YEAR) | NEXT LARGEST | SMALLEST \|RD\| | RANGE \|RD\| |
|---|---|---|---|---|---|---|
| N.DAKOTA | 10 | 30 | 23.1 (1972) | -16.9 | 0.0 | 23.1 |
| | 20 | 30 | 20.9 (1974) | 13.4 | 0.0 | 20.9 |
| | 30 | 20 | 17.6 (1974) | -12.6 | 0.5 | 17.1 |
| | 40 | 30 | -11.0 (1976) | -10.8 | -1.5 | 9.5 |
| | 50 | 50 | -24.3 (1977) | 20.8 | 5.4 | 18.9 |
| | 60 | 20 | 15.9 (1974) | -10.2 | -0.6 | 15.4 |
| | 70 | 20 | -20.4 (1973) | -16.1 | -1.4 | 19.0 |
| | 80 | 70 | 69.0 (1974) | 29.7 | -1.8 | 67.1 |
| | 90 | 50 | 37.2 (1974) | 25.4 | 0.6 | 36.6 |
| STATE MODEL | | 10 | 14.6 (1974) | -10.0 | 0.0 | 14.6 |
| CRDS AGGR. | | 20 | 17.5 (1974) | 10.8 | 1.2 | 16.3 |
| MINNESOTA | 10 | 10 | 11.3 (1974) | 7.6 | 1.9 | 9.4 |
| | 40 | 80 | 41.6 (1978) | 29.5 | -1.7 | 39.9 |
| STATE MODEL | | 20 | 13.7 (1978) | 11.9 | 3.2 | 10.5 |
| CRDS AGGR. | | 30 | 12.7 (1974) | 12.4 | -2.3 | 10.4 |
| REGION | | | | | | |
| CRDS AGGR. | | 20 | 16.3 (1974) | 10.6 | 0.5 | 15.8 |
| STATES AGGR. | | 10 | 12.8 (1974) | -8.6 | 0.0 | 12.8 |

Figure 3. Percent of test years (1970-1979) the absolute value of the relative difference from the CEAS spring wheat models is greater than ten percent. Darker shades indicate CRDs with higher production.

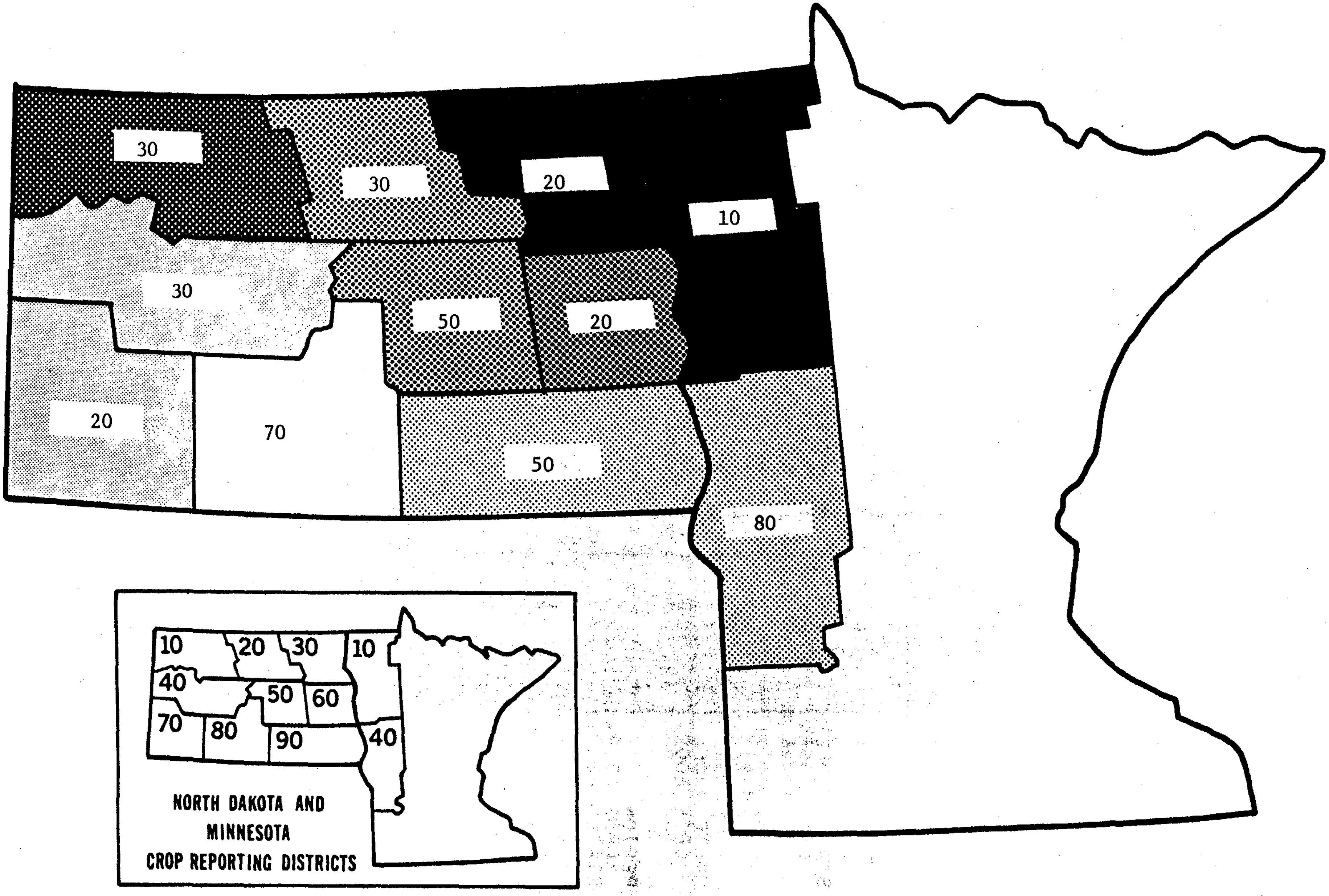


Figure 4. Largest absolute value of the relative difference from the CEAS spring wheat models during the test years 1970-1979. Darker shades indicate CRDs with higher production.

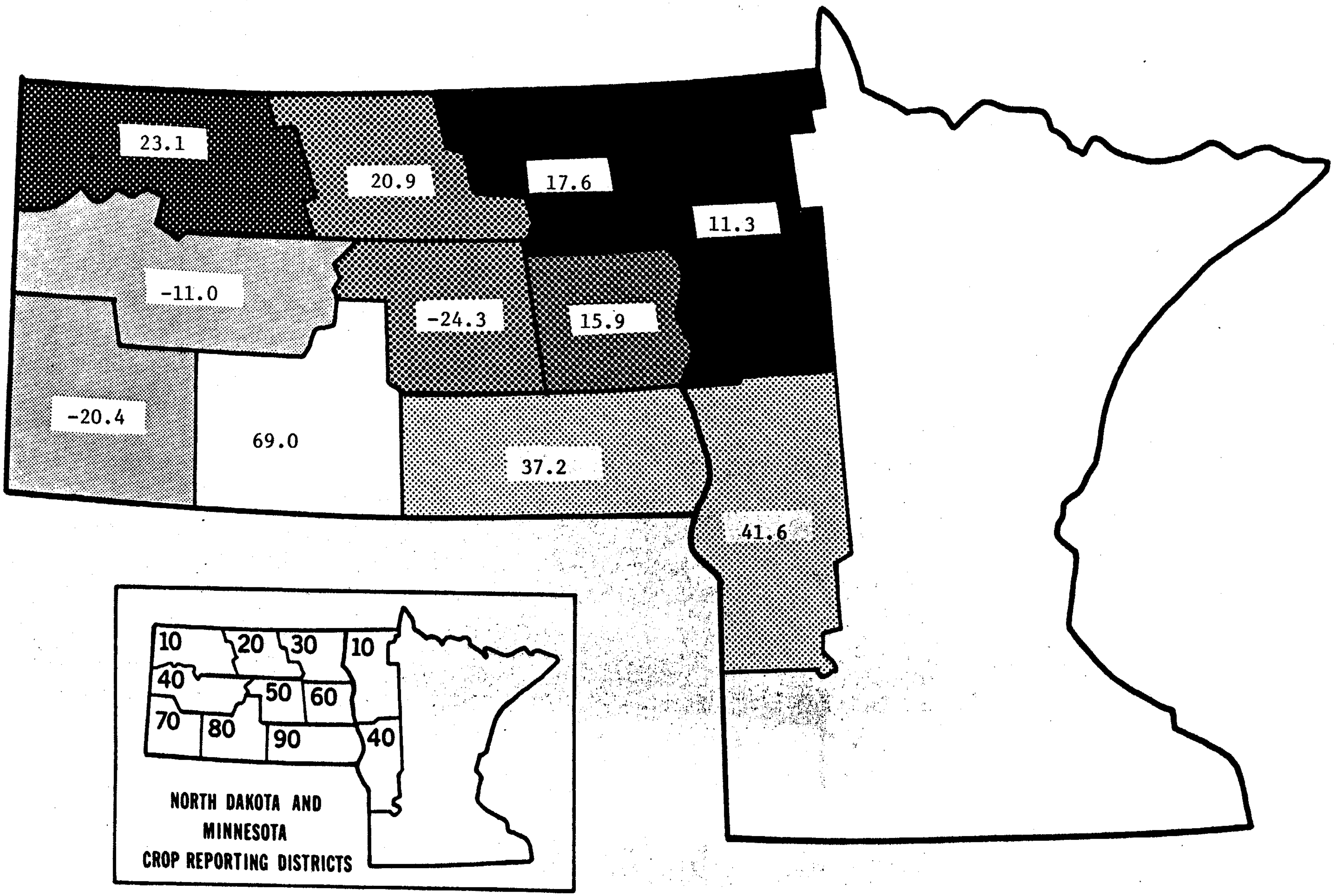


Figure 5. Next largest absolute value of the relative difference from the CEAS spring wheat models during the test years 1970-1979. Darker shades indicate CRDs with higher production.

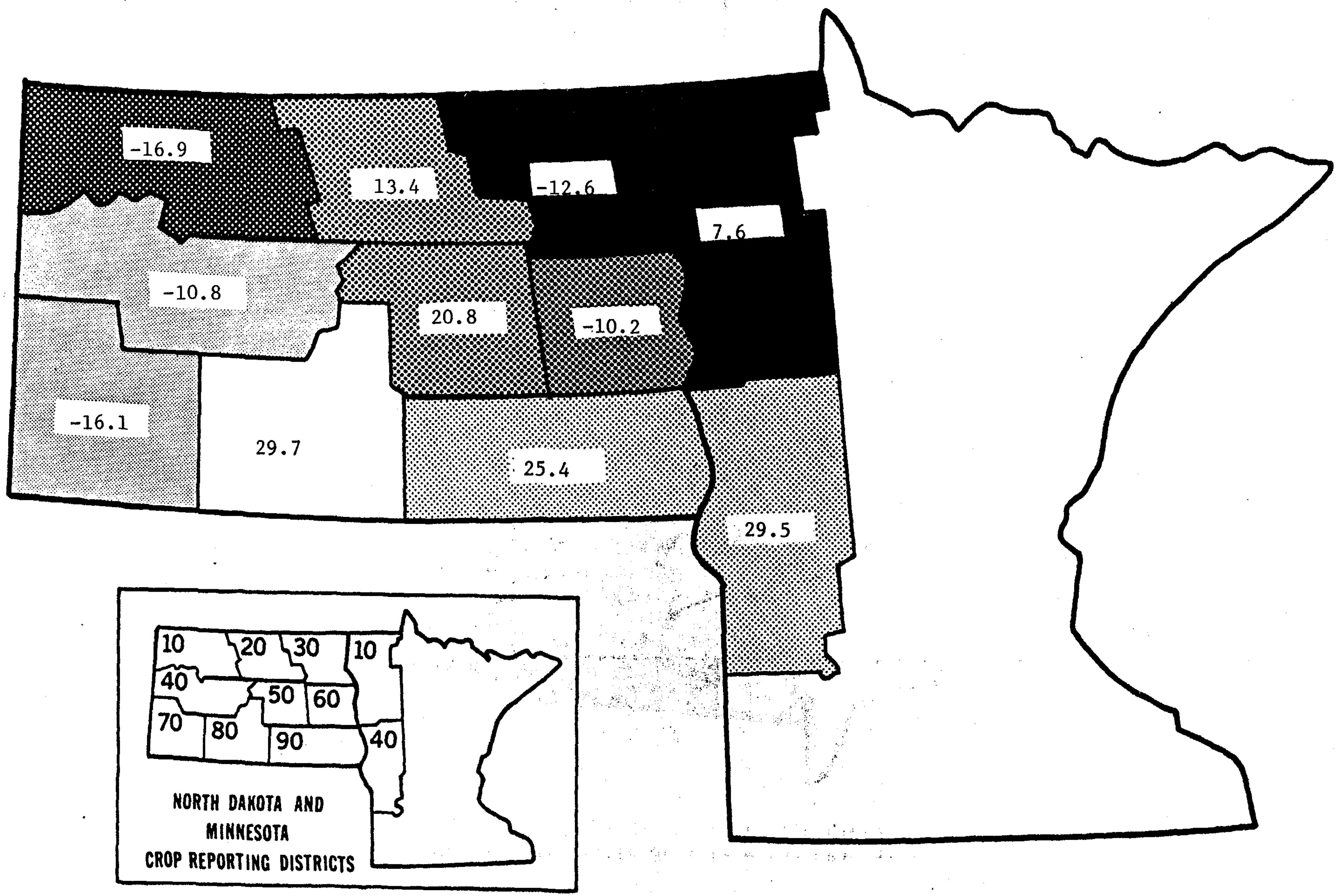


Figure 6

North Dakota State Model, Actual and Predicted Spring Wheat Yields for the Test Years 1970-1979 (Quintals/Hectare)

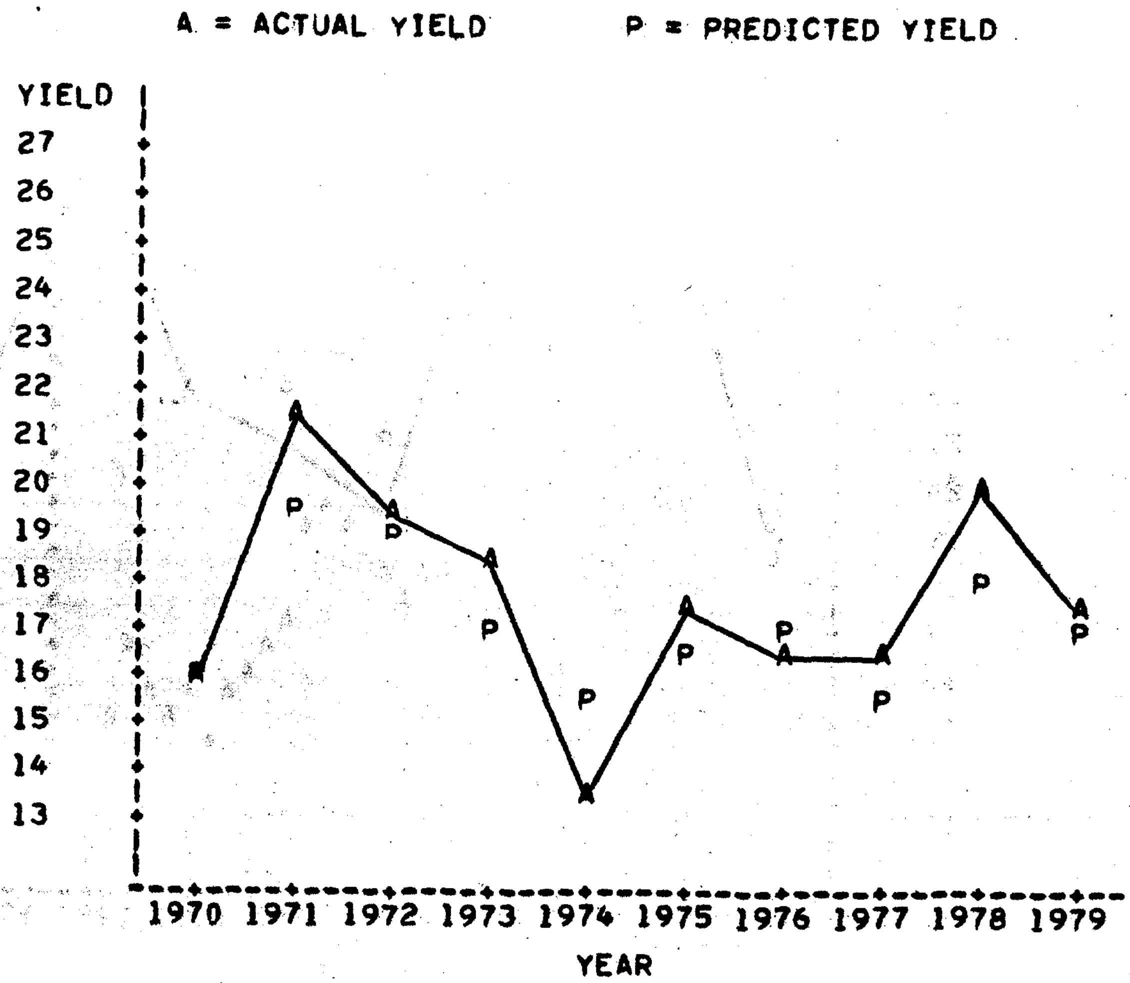


Figure 7

Minnesota State Model, Actual and Predicted Spring Wheat Yields for The Test Years 1970-1979 (Quintals/Hectare)

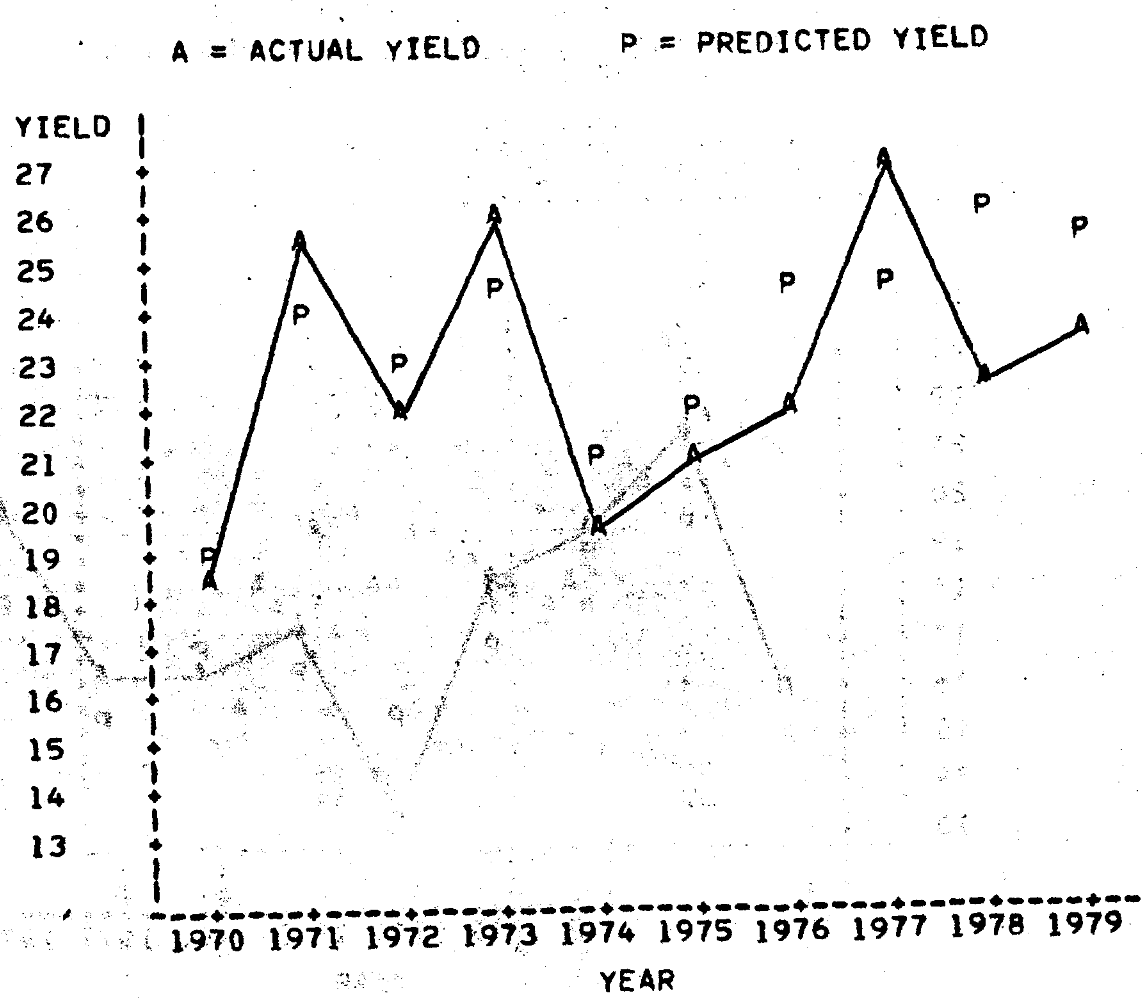


TABLE 4
INDICATORS OF YIELD RELIABILITY
BASED ON ACTUAL AND PREDICTED YIELDS

CEAS MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

| STATE CRD | PERCENT OF YEARS DIRECTION OF CHANGE IS CORRECT FROM PREVIOUS YEAR | FROM BASE PERIOD | PEARSON CORR. COEF. |
|---|---|---|---|
| N.DAKOTA 10 | 78 | 71 | 0.70 |
| 20 | 78 | 100 | 0.92 |
| 30 | 78 | 71 | 0.74 |
| 40 | 78 | 71 | 0.90 |
| 50 | 89 | 57 | 0.61 |
| 60 | 89 | 57 | 0.78 |
| 70 | 78 | 57 | 0.67 |
| 80 | 67 | 86 | 0.50 |
| 90 | 56 | 100 | 0.54 |
| STATE MODEL | 78 | 57 | 0.89 |
| CRDS AGGR. | 78 | 57 | 0.81 |
| MINNESOTA10 | 89 | 86 | 0.94 |
| 40 | 67 | 57 | 0.41 |
| STATE MODEL | 67 | 57 | 0.74 |
| CRDS AGGR. | 56 | 86 | 0.74 |
| REGION | | | |
| CRDS AGGR. | 56 | 57 | 0.81 |
| STATES AGGR. | 67 | 71 | 0.88 |

Figure 8. Percent of test years (1970-1979) the direction of change from the previous year in yield as predicted by the CEAS spring wheat models agrees with the direction of change in the actual yield. Darker shades indicate CRDs with higher production.

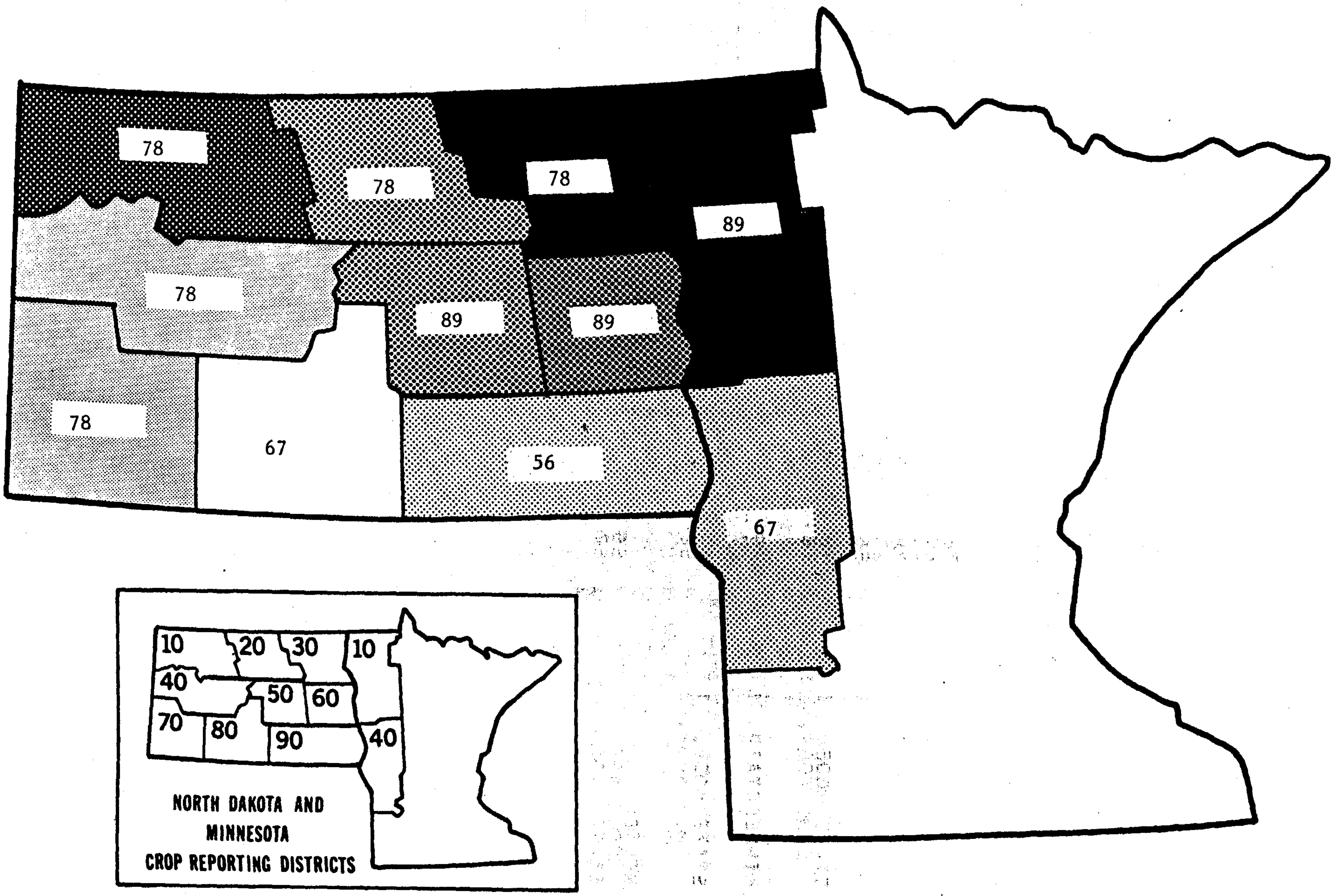


Figure 9. Percent of test years (1970-1979) the direction of change from the previous three years average yield as predicted by the CEAS spring wheat models agrees with the direction of change in the actual yield. Darker shades indicate CRDs with higher production.

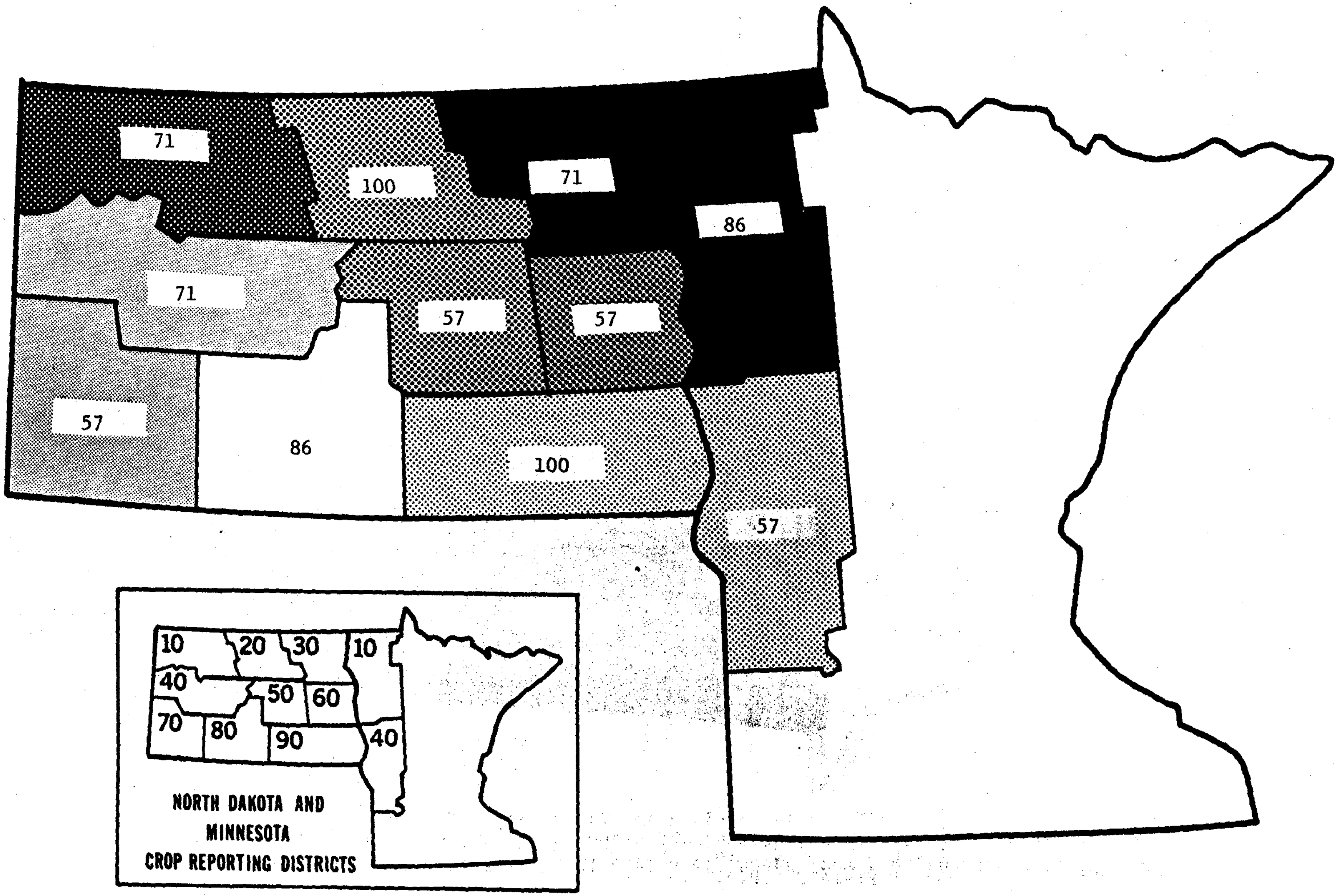
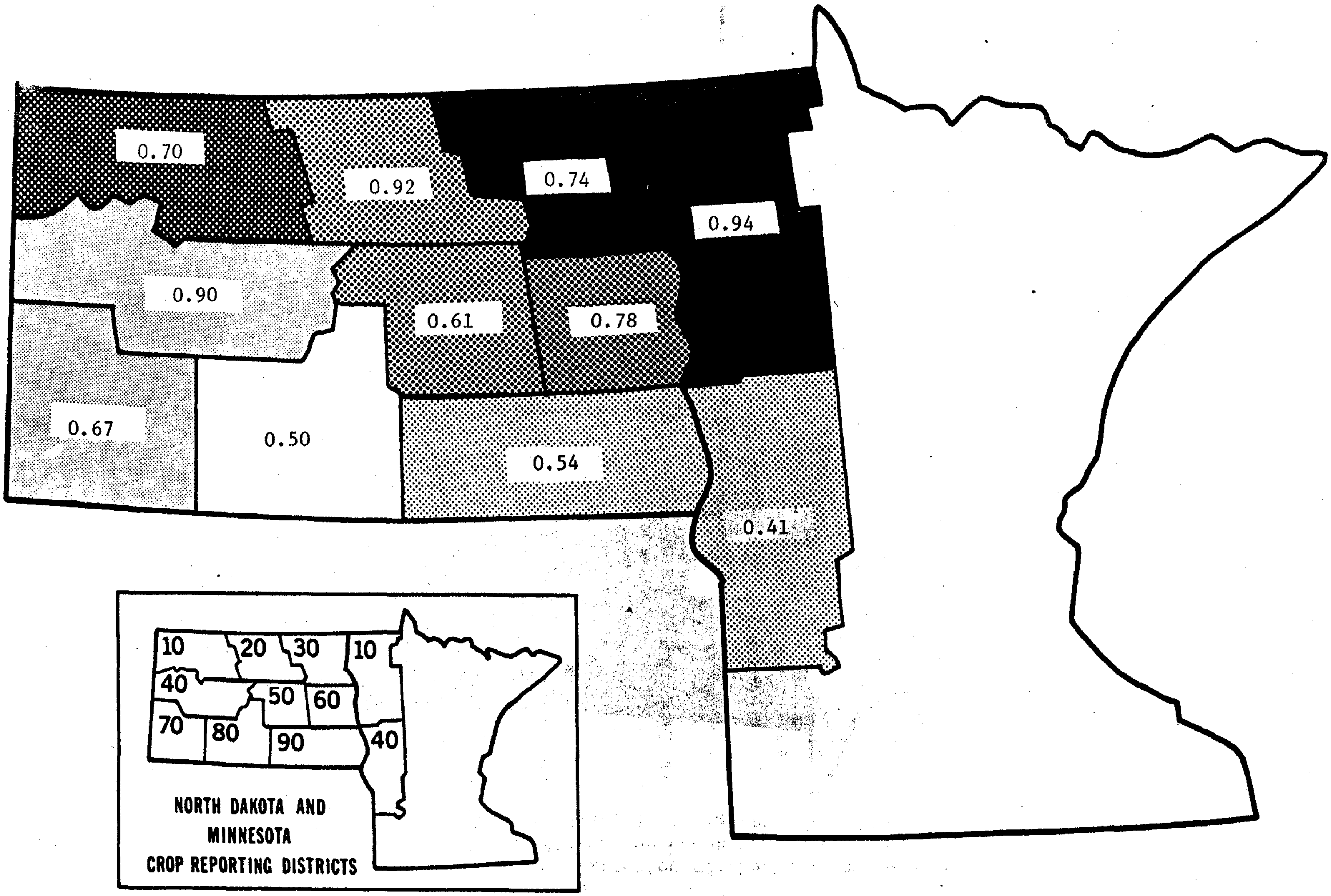


Figure 10. Pearson correlation coefficient between actual yield and yield as predicted by the CEAS spring wheat models for the test years (1970-1979). Darker shades indicate CRDs with higher production.



although the predicted yields in both states increase in 1971 and decrease in 1974, they do not go as high or as low as the actual yields. Also, note the insensitivity of the Minnesota predicted yields in 1978 and 1979 to the lower actual yields.

The ND state model Pearson correlation coefficient is slightly higher than the results for CRDs aggregated. The coefficient at the region level is slightly higher when aggregating from the state models.

Change of predicted yield from previous forecasts within the current year was not investigated.

## Precision During Independent Tests Cannot Be Predicted From Indicators of Base Period Precision

Certain statistics generated from the regression analysis of the base period data are often used to provide some indication of expected yield reliability. However, these statistics only reflect how well the model describes the data used to generate the model, i.e., fit of the model, rather than how well the model can predict given new data. Therefore, it is important to compare these indicators of fit of the model to the independent indicators of yield reliability discussed in the preceding sections. In this way, one can see how these base period indicators of fit of the model do or do not correspond to independent test indicators of yield reliability.

One indicator of yield reliability, the mean square error (MSE), is the sum of squared d values ($d = \hat{Y} - Y$) for the independent test years divided by the number of test years (Table 2). The direct analogue for the model development base period is the residual mean square. The residual mean square is obtained by first generating the usual least squares prediction equation using the base period years. Then instead of predicting the yield for the following test year, yields are predicted for each of the base period years. The residual mean square is the sum of squared d values for these base period years divided by the appropriate degrees of freedom (number of years minus number of parameters estimated in fitting the model). Whereas one value of MSE is generated for each geographic area over the entire test period, a value of the residual mean square is generated for each base period corresponding to a test year in that area. The low, high, and average of the base period values for each area are given in Table 5.

The MSE values in Table 2 are also given in Table 5. The independent test MSEs are smaller than the lowest value of the residual mean square for the base period in most cases. The exceptions are CRDs 50, 80, and 90 in North Dakota and CRD 40 and the state model in Minnesota. In four of these five cases, the independent test MSE is larger than the highest value of the base period residual mean square. In conclusion, the independent test MSE is seen to be sometimes larger and sometimes smaller than the base period residual mean square.

## TABLE 5
## RESIDUAL MEAN SQUARE AS AN INDICATOR OF THE FIT OF THE MODEL BASED ON THE MODEL DEVELOPMENT BASE PERIOD

CEAS MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

| STATE | CRD | BASE PERIOD RESIDUAL MEAN SQUARE LOW | HIGH | AVERAGE | INDEPENDENT TEST MSE |
|---|---|---|---|---|---|
| N.DAKOTA | 10 | 5.37 | 5.94 | 5.68 | 4.30 |
| | 20 | 3.86 | 4.34 | 4.08 | 2.13 |
| | 30 | 4.83 | 5.68 | 5.24 | 2.61 |
| | 40 | 4.49 | 5.44 | 4.92 | 1.36 |
| | 50 | 4.34 | 4.73 | 4.56 | 6.15 |
| | 60 | 4.72 | 5.39 | 5.01 | 2.72 |
| | 70 | 3.90 | 4.16 | 4.03 | 3.40 |
| | 80 | 4.30 | 5.09 | 4.72 | 7.99 |
| | 90 | 2.92 | 3.41 | 3.17 | 6.33 |
| STATE MODEL | | 3.64 | 4.20 | 3.88 | 1.60 |
| MINNESOTA | 10 | 3.27 | 3.92 | 3.59 | 1.58 |
| | 40 | 5.49 | 7.81 | 6.18 | 17.49 |
| STATE MODEL | | 3.07 | 3.48 | 3.24 | 3.46 |

## TABLE 6
## CORRELATION BETWEEN OBSERVED AND PREDICTED YIELDS AS AN INDICATOR OF THE FIT OF THE MODEL BASED ON THE MODEL DEVELOPMENT BASE PERIOD

CEAS MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

| TEST STATE | CRD | BASE PERIOD CORRELATION COEF. LOW | HIGH | AVERAGE | INDEPENDENT CORR. COEF. |
|---|---|---|---|---|---|
| N.DAKOTA | 10 | 0.91 | 0.93 | 0.92 | 0.70 |
| | 20 | 0.91 | 0.93 | 0.93 | 0.92 |
| | 30 | 0.90 | 0.93 | 0.91 | 0.74 |
| | 40 | 0.90 | 0.93 | 0.92 | 0.90 |
| | 50 | 0.92 | 0.93 | 0.93 | 0.61 |
| | 60 | 0.90 | 0.92 | 0.91 | 0.78 |
| | 70 | 0.91 | 0.93 | 0.92 | 0.67 |
| | 80 | 0.87 | 0.89 | 0.88 | 0.50 |
| | 90 | 0.92 | 0.93 | 0.93 | 0.54 |
| STATE MODEL | | 0.90 | 0.93 | 0.92 | 0.89 |
| MINNESOTA | 10 | 0.89 | 0.95 | 0.93 | 0.94 |
| | 40 | 0.83 | 0.88 | 0.86 | 0.41 |
| STATE MODEL | | 0.90 | 0.95 | 0.93 | 0.74 |

Another indicator of yield reliability is the correlation coefficient, r, between the observed and predicted yields for the independent test years (Table 4). It is desirable for r to be close to +1, even though it can be negative. The analogue for the model development base period is the square root of $R^2$, the coefficient of multiple determination. The square root of $R^2$ (expressed as a proportion), $R(0 \leq R \leq 1)$, may be interpreted as the correlation between observed and predicted values for the base period years. The low, high, and average values of R for each geographic area are given in Table 6. The average ranges from 0.86 to 0.93.

The Pearson correlation coefficient values in Table 4 are also shown in Table 6. They range in value from 0.41 to 0.94. With the exception of CRDs 20, 40 and the state model in North Dakota and CRD 10 in Minnesota, the independent test period correlation coefficient is much smaller than the values of R from the base period. The value of R (and thus $R^2$) for a model development base period is thus often seen to overestimate the independent performance of these models.

## Models Are Objective For Short-Term Use in North Dakota and Minnesota

The form of each model (or the variables included) was determined by regression analysis performed on all of the data available at the time of model development. In order to predict the yield for a future year, the value for trend and any weather-related variables included in the model would be calculated and used along with the regression equation coefficient values which were derived during model development. This is an objective process as all of the variables and the form of the model are clearly defined.

However, as more yield/weather data became available, the model development process would, presumably, be repeated. Redevelopment could affect the form of the model in two ways: (1) trend may need to be re-specified in keeping with the current impact of the technology on yield and/or (2) different terms may be selected for inclusion in the model because of the impact of the additional data. Since both of these changes involve some subjective decisions, it is not clear that someone other than the model developer would make them in the same way as the model developer would or that the resulting models could be considered to be the same models as the ones evaluated in this paper.

If similar models were to be developed for use in other geographic areas, an additional consideration would be the specification of the available water capacity for the soil moisture budget. An objective procedure for determining the capacity is not given.

## More Scientific Evidence is Needed to Demonstrate Consistency With Scientific Knowledge

The model developer uses three types of variables: (1) year, as a surrogate for technology, (2) derived meteorological variables, such as temperatures expressed as deviations from normal, and (3) derived agroclimatic variables, for example, the difference between precipitation and potential evapotranspiration. Each of these variable types will be discussed as they were considered for model development and as they actually appear in the models.

Trend terms are an important component of trend and monthly weather data models. Usually, they are the first terms selected by the stepwise procedure and account for more than half of the total variation in yield explained by the model (49-78 percent for these CEAS models). Also, the specification of trend determines the residuals of trend which are assumed to be dependent on the meteorological and agroclimatic variables. Therefore, if trend is improperly handled in a model, results may be substantially affected.

For the models evaluated, changes in yield due to technology are assumed to be continuous piecewise linear functions of time (year). Piecewise functions allow the year-to-year contribution to yield from technology and other non-weather factors to be different over various time periods. In fact, the contribution may be zero over some portions of time. A period of such flat trend indicates no increases (or decreases) in yield due to technology (or non-weather) factors. As long as one is not able to consider the various component parts of technology, this form of the model seems reasonable. However, it does not allow for discontinuities in the yield level due to sudden shifts in technology.

Trend terms were selected for inclusion in the models by the stepwise procedure, as were the weather terms. Three trend terms were constructed for possible inclusion in the North Dakota models. The first term increases from 1955 to 1966, the second from 1966 to 1973, and the third from 1973 on. Only one trend term was considered for the Minnesota models. It increases from 1955 to 1978. The model developer subjectively determined these change-over points from plots of yield versus year. (An addendum to the original CEAS report notes that these trends are similar to those used in LACIE.) The Minnesota term and the first North Dakota term were selected by all models in their respective states. The second North Dakota term was only selected by the model for CRD 90.

No evidence of scientific knowledge is given to justify the change-over points in trend. Although plots of yield versus time (Figures 11 and 12) do indicate increased yields in North Dakota from the early to mid 50's until the early 70's, it is difficult to visually discern a distinctly different rate of change beginning in 1966 and ending in 1973. The last trend term in North Dakota (not selected) was constructed so that yield would continue to increase as a function of time past the final model development year (1978). The trend term in Minnesota was constructed so that yield is not affected by year after 1978. No reason is given for this difference in approach.

The numeric values of the coefficient for the trend term in the three Minnesota models are roughly equivalent (about 0.6). However, in North Dakota the numeric values of the coefficient for the 1955-1966 trend term ranges from about 0.6 in CRDs 80 and 90 to about 1.0 in CRDs 30 and 50.

Figure 11

North Dakota U.S.D.A. Reported Spring Wheat Yields, 1931-1979 (Quintals/Hectare)

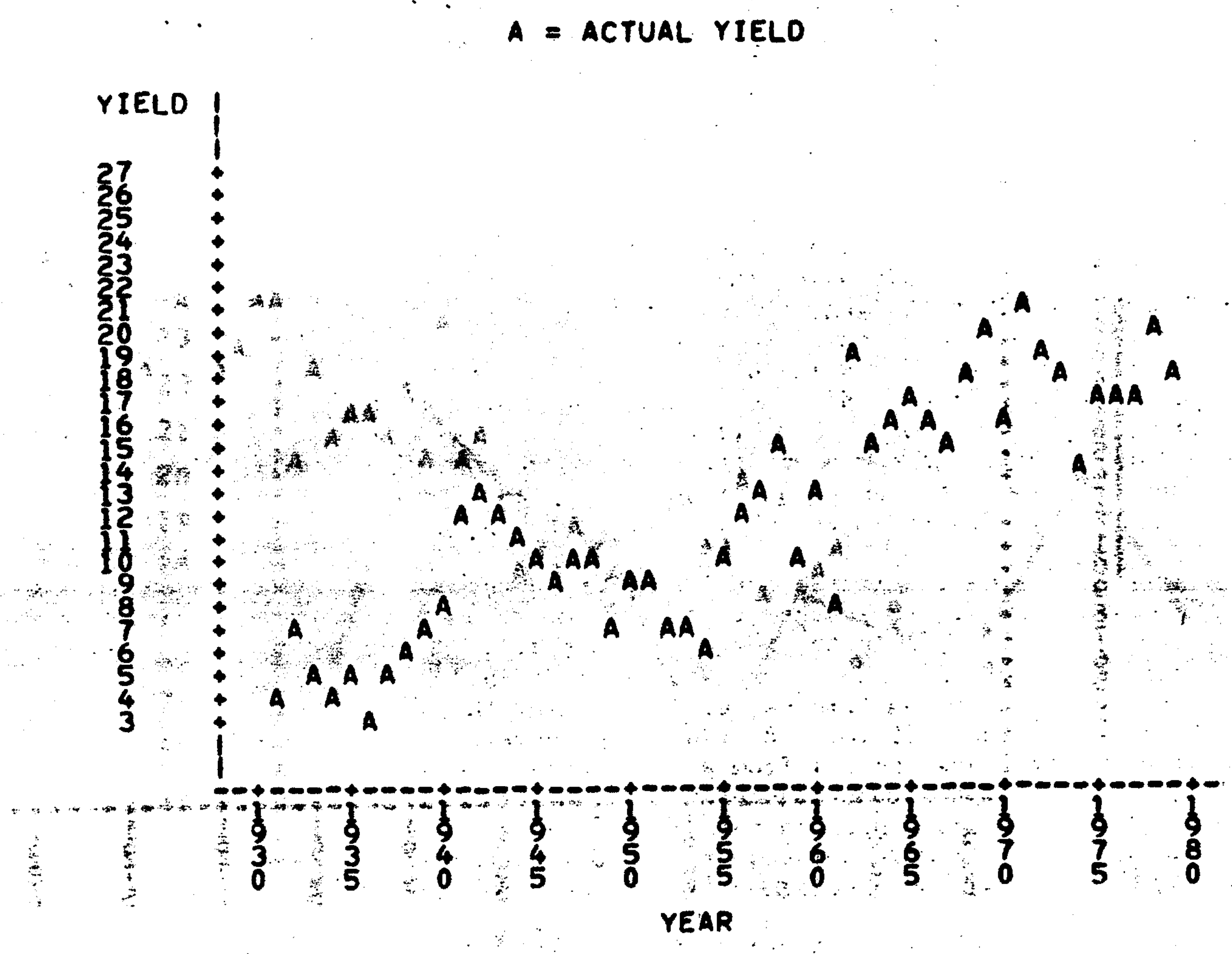
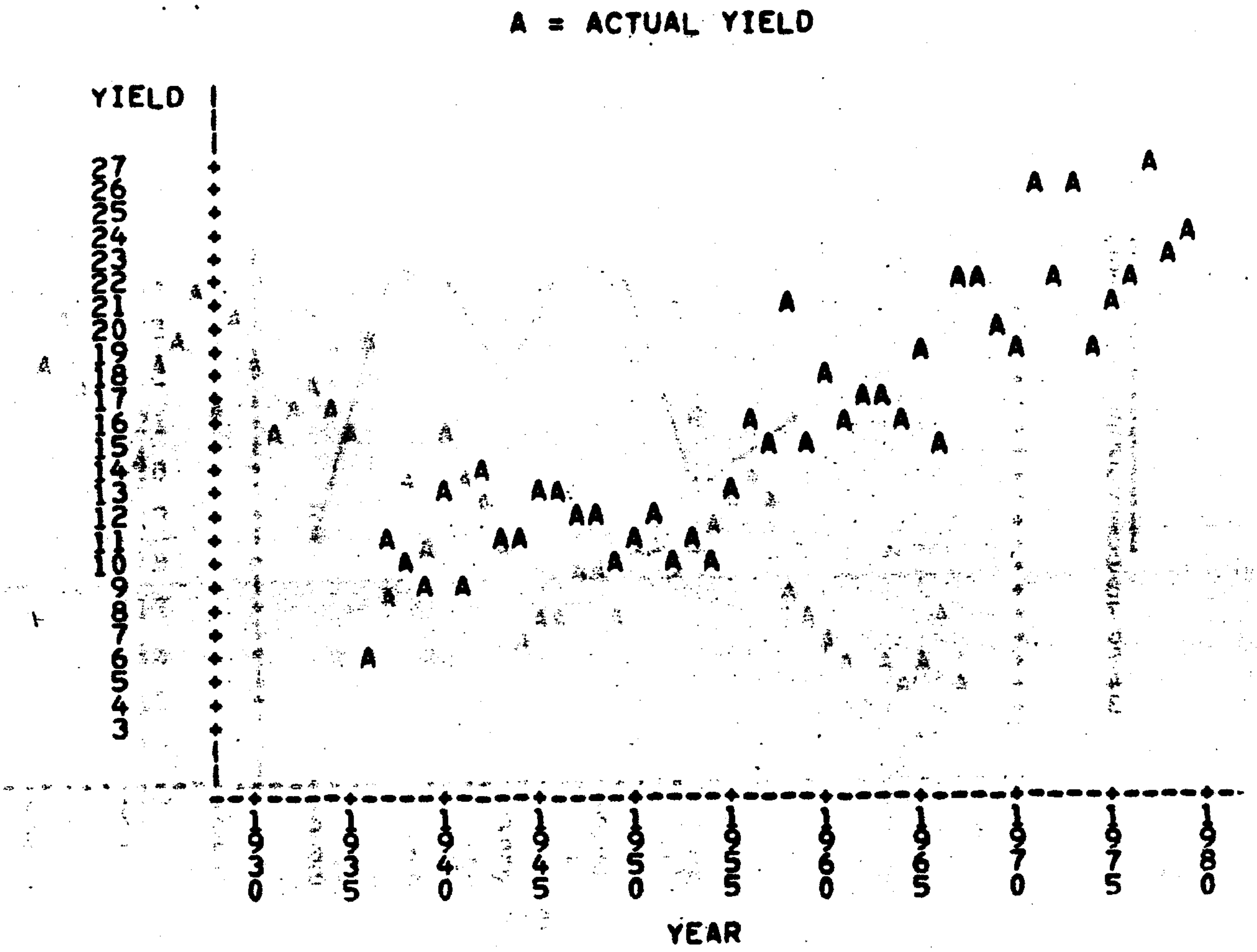


Figure 12

Minnesota U.S.D.A. Reported Spring
Wheat Yields, 1936-1979
(Quintals/Hectare)



One would like to see some scientific evidence presented to support this difference. One would also like to see some scientific evidence to support the inclusion of the additional trend term (1966-1973) in only one ND model (CRD 90).

In terms of consistency with scientific knowledge, it would be most desirable to not have to use year as a surrogate for technology and/or other non-weather factors. However, if it must be used, then one would like to see the change-over points chosen objectively and in such a way that scientific evidence could be used as supporting evidence. Even if change-over points must be subjectively determined, they should be clearly linked to scientific evidence on actual changes in technology and other non-weather factors. This would also allow some guidelines to be developed for the choice of change-over points when model re-development occurs in future years or in other geographic areas.

As mentioned previously, if technological improvements in crop yields are modeled by a trend term based on year, the manner in which trend appears in the model can have a large impact on yield estimates and forecasts. It is not at all clear that entering trend and weather as distinct variables in a single regression equation clearly separates the impact of weather and non-weather influences on yield. More research needs to be done on alternate methods of distinguishing the effects of weather and technology.

This CEAS spring wheat model uses monthly weather values. Of course, there is little year-to-year agronomic correspondence between the beginning and ending of a calendar month and the beginning and ending of stages of development for a wheat plant (and thus its changing temperature and moisture requirements). Also, wheat plants do not begin developmental stages at the same time each year. Therefore, an inherent difficulty exists in working with monthly weather data.

Another problem in using a single monthly weather value for a CRD or state is the underlying assumption that each year the value is representative of the entire area for the entire month. In one year the value may be more representative of the conditions in one part of the area or in one part of the month and in another year the same value may be more representative of another area or part of the month. Variables involving rainfall could be particularly affected by these dissimilarities from year-to-year. Of course, these comments apply to any model constructed from variables of this type, not just the CEAS models.

Monthly meteorological variables available on a climatic division basis (corresponding to a crop reporting district) are average temperature and total precipitation. The monthly precipitation values are also summed to obtain cumulative precipitation terms. The average value of these three types of meteorological variables is subtracted from its value for the month or, in the case of cumulative precipitation, its value over several months.

Terms were selected for inclusion in the models from these various derived meteorological variables using the stepwise procedure. Of course, in using the stepwise procedure to fit CRD models, the question arises as to why a term is selected by the model for a particular CRD but not by any of the surrounding CRDs. No scientific explanation is presented.

The meteorological variables were considered as deviations from normal, both linear and quadratic. The implication of the quadratic form is that a large deviation from normal, in either a positive or negative direction has an equal impact on the yield. Evidence is not given to support the assumption.

The June and July temperature deviation from normal terms selected by the models bore negative coefficients in each case (-0.4 to -0.9 for June and -0.6 to -1.3 for July). This demonstrates the expected association between higher than average temperatures in June and July and lower yields. No discussion was presented describing possible relationships between the magnitude of the temperature coefficients for each CRD and some other meaningful CRD variable, such as average annual precipitation or temperature. In the ND CRD 40 model, the May temperature deviation from normal term has a positive coefficient (0.6). No explanation is given for the positive coefficient in an earlier month.

The interpretation of the inclusion of some precipitation terms is clouded by the fact that some agroclimatic variables are also calculated which use monthly total precipitation. For example, in ND CRD 10, the coefficient for July rainfall as a deviation from normal is -.3. This indicates an unexpected association between above average rainfall in July and lower yields. However, July precipitation also enters the model through the variable P/PET which has a coefficient of 47. This large positive coefficient indicates an association between large amounts of rainfall and higher yields. So the two terms must be considered simultaneously.

Cumulative precipitation expressed in raw form is usually summed from September of the previous year and enters the North Dakota models with a positive coefficient. The positive coefficients indicate an association between more cumulative precipitation and higher yields. In the Minnesota state model, the precipitation is cumulated from October instead of September. No scientific explanation is made. Also, the coefficient is negative. The squared deviation from normal cumulative precipitation terms enter with negative coefficients indicating lower yields associated with either extreme of above or below average cumulated rainfall.

The agroclimatic variables considered enter into the models in a sporadic fashion. Each of the three quantities was chosen at least once in some month by some CRD or state model. No scientific explanation is given as to why it was appropriate for June P-PET to be the selected variable in another CRD. Also, no reason is given why these variables were not also considered as deviations from normal or in the quadratic form. Of course, other agroclimatic variables, such as soil moisture budget contents, could also have been considered.

The ratio of ET to CAFEC(ET) enters the models with a positive coefficient. This indicates a larger than normal supply of moisture is associated with higher yields. The difference, P-PET, for June and July enters one model. Both terms have positive coefficients. Again this indicates that a greater supply of moisture as compared to demand is associated with higher yields. The ratio, P/PET, enters two models with positive coefficients and two models with negative coefficients. A positive coefficient indicates that the more the supply of moisture exceeds the demand, the higher the yield. The negative coefficients indicate a lower yield associated with precipitation exceeding demand. Again, caution should be given that the interpretation of the coefficients of these variables must be tempered if a precipitation term for the same month is also in the model.

Since these agroclimatic terms are included to represent stress conditions, one might have expected them to be constructed so that large values represent high stress rather than the absence of stress. Also, it is surprising that some threshold value for stress was not found above which any further effect on yield would be negligible.

In order to calculate the agroclimatic variables, PET and a soil moisture budget are estimated. ET is estimated using PET, P, and the contents and capacity of the soil moisture budget. Thornwaite's (1948) procedure is used to calculate monthly PET. The consideration of other procedures, such as a modified Blaney-Criddle, is not mentioned. Running a soil moisture budget on a monthly basis is a difficult task. This is mainly because runoff can not be determined accurately without daily precipitation as input to the budget. An available water capacity of ten inches (254 mm) is assumed for all CRDs and both states. Palmer (1965) recommends ten inches as a reasonable figure for Central Iowa. He assumes six to eight inches is more appropriate for western Kansas. No scientific evidence is presented in the present case to justify the ten inch budget in North Dakota and Minnesota and its uniform value in every CRD.

Values of the meteorological deviation from normal and agroclimatic variables to be used in the state models are computed as weighted averages of the values used in the CRD models. Another way to compute them would be to compute the weighted average of the basic meteorological variables, monthly average temperature and total precipitation, and then compute the derived variables at the state level in the same manner as they were computed at CRD level. No scientific evidence is presented to show a preference for performing the aggregation one way or the other.

Finally, one would like to see the use of a variety of methods for variable selection and parameter estimation. In the field of regression analysis, increasing use is being made of new diagnostic, robust estimation and variable selection techniques. The use of these new techniques does not guarantee better models but should, at least, lead to a better understanding of the limitations of the models.

### Model Re-Development Would Be Required to Predict Other Than CRD and State Yields in North Dakota and Minnesota

In theory, a CEAS trend and monthly weather date model could be developed for any geographic area and for any level of detail as long as historic values of year, yield, and monthly average temperature and total precipitation were available. However, the complete model development process would have to be followed in order to develop models for other than CRD or state geographic subdivisions in North Dakota and Minnesota or for areas outside those two states. So the models are only adequate for those geographic areas for which they have been developed. Also, the models discussed and evaluated here use climatic division weather data. Each climatic division in North Dakota uses information from between eight to seventeen weather stations. Comparable results may not be obtained in areas using less dense networks.

## Timely Estimates Can Be Made Using Approximated Weather Data

Pre-season models using only trend were developed for each CRD and state. The development of models using weather data available through each of the months March through August was also investigated. However, six different models were not necessarily derived for each CRD and state. In most cases, the models for some of the adjacent months did not contain different variables so that, for example, the July model might be identical to the June model. In one case (ND CRD 80), the end of season yield estimate is obtained using the June model.

It takes about three months after the end of a month to obtain that month's average temperature and total precipitation for the climatic divisions in North Dakota and Minnesota from the National Climatic Center in Asheville, North Carolina. However, estimates of these climatic division values can be prepared earlier. These weather data approximations could be used in the regression equations to obtain yield estimates in the first week of the month following the month for which the weather data pertains. The yield estimate will not change if the model for a particular month is the same as for the previous month.

## Trend and Monthly Weather Data Models are not Costly to Operate

Operational costs of running these models through a growing season in North Dakota and Minnesota are not high. The monthly weather data (average temperature and total rainfall) obtained on a timely basis is currently prepared for other users on a routine basis, so that conceptually the cost could be shared. All that is required to obtain the yield estimates is to have someone responsible for acquiring the weather data and performing the regression equation calculations. The necessary computer programs are written in SAS and could be run on a computer system having that capability.

The more expensive part of the process is the maintenance of the historic agricultural and meteorological data bases and the re-development of models as required. The maintenance of the data bases requires the part-time efforts of persons familiar with meteorological data, agricultural data, and the computer system being used. The re-development of the models in future years, incorporating more recent yield and weather data, would require the skills of a person familiar with statistical regression methodology and agronomic modeling using meteorological variables.

It is difficult to say how expensive it would be to develop a model for a geographic area other than North Dakota or Minnesota. The availability and form of the weather and yield data would be the determining factors.

### Models are Easy to Understand and Use

The variables contained in these trend and monthly weather data models for spring wheat yield estimation are fairly simple and easy to understand. A computer program would normally be used to calculate at least the values of the stress variables. The contents of the soil moisture budget would need to be saved from the previous year unless it could be assumed that the budget was filled to capacity over the winter months. It may be confusing to users to have three different kinds of similarly defined stress variables appearing in the models for various CRDs. Also, the user might expect large values of a stress variable to indicate more stress instead of less. Interpretation of some coefficients may be difficult in models which include for the same month precipitation both as a deviation from long term average and as part of a stress variable.

### Standard Errors of Prediction Provide Poor Current Measures of Modeled Yield Reliability

The CRD, state, and region values for the Spearman correlation coefficient between the estimate of the standard error of a predicted yield value and the absolute value of the difference between the predicted and actual yield are computed. They are given in Table 7. The CRD correlation coefficient values are displayed in Figure 13. In 5 of 11 CRDs, and in both state models, the correlation coefficient is negative. The largest positive value is 0.70 for ND CRD 90. Thus, $s_{\hat{Y}}$ does not provide a good measure as to how close the predicted values will be to the actual values. In a given geographic area, instances of test years with smaller prediction intervals about the yield being predicted are all too often associated with larger observed discrepancies between the actual and predicted value. The accuracy of a predicted yield cannot be reliably judged using $s_{\hat{Y}}$.

## CONCLUSIONS

At the state level, the bias of these models is generally less than one quintal/hectare and the standard deviation is between one and two quintals/hectare. Performance in four of the CRDs is less reliable than in the other seven. For short-term use in North Dakota and Minnesota, the models are objective and adequate (in terms of coverage). Consistency with scientific knowledge could be more thoroughly documented. Timely yield forecasts and estimates can be made during the growing season, by deriving approximations to climatic division weather values. The models are not costly to operate but re-development costs must be considered. The models are understandable and easy to use. The model standard errors of prediction do not provide a useful current measure of modeled yield reliability.

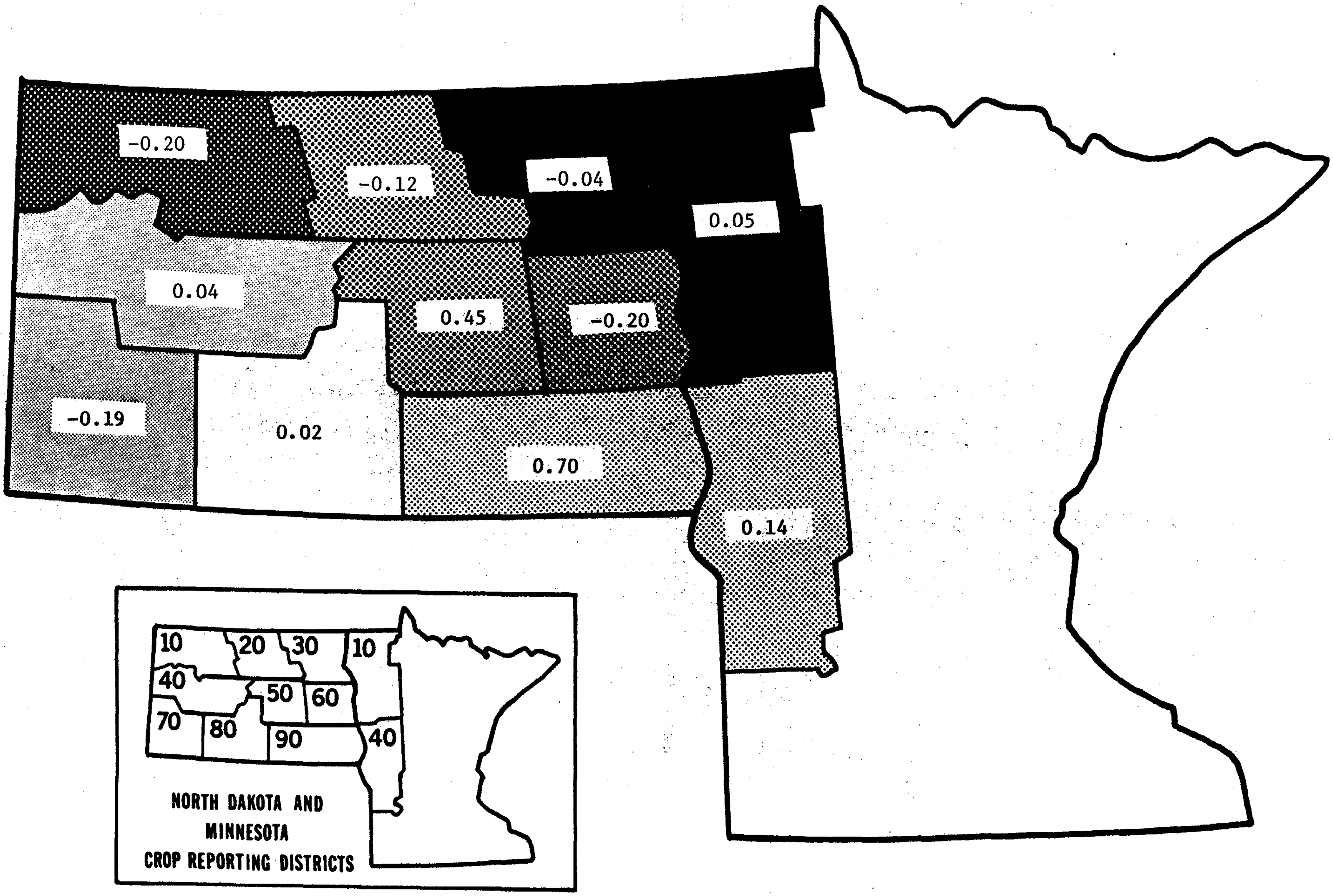
TABLE 7
CURRENT INDICATION OF
MODELED YIELD RELIABILITY

AGREEMENT BETWEEN BASE PERIOD PREDICTED
AND TEST YEAR ACTUAL ACCURACY

CEAS MODEL - SPRING WHEAT
NORTH DAKOTA AND MINNESOTA

| STATE | CRD | SPEARMAN CORRELATION COEF. |
|---|---|---|
| N.DAKOTA | 10 | -0.20 |
| | 20 | -0.12 |
| | 30 | -0.04 |
| | 40 | 0.04 |
| | 50 | 0.45 |
| | 60 | -0.20 |
| | 70 | -0.19 |
| | 80 | 0.02 |
| | 90 | 0.70 |
| STATE MODEL | | -0.17 |
| MINNESOTA | 10 | 0.05 |
| | 40 | 0.14 |
| STATE MODEL | | -0.91 |

Figure 13. Spearman correlation coefficient between the estimate of the standard error of a predicted value from the CEAS spring wheat base period model and the absolute value of the difference between the predicted and actual yield in the test years (1970-1979). Darker shades indicate CRDs with higher production.



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## APPENDIX

**Variables Included in CRD and State CEAS Models for Spring Wheat Yields in North Dakota and Minnesota**
**+ Means a Positive Coefficient and - Means a Negative Coefficient**

| | North Dakota | | | | | | | | | | Minnesota | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | State | 10 | 40 | State |
| **Trend Variables** | | | | | | | | | | | | | |
| Linear between 1955 and 1966 | + | + | + | + | + | + | + | + | + | + | | | |
| Linear between 1966 and 1973 | | | | | | | | | + | | | | |
| Linear between 1955 and 1978 | | | | | | | | | | | + | + | + |
| **Meteorological Variables** | | | | | | | | | | | | | |
| Temperature DFN[1)] - May | | | | + | | | | | | | | | |
| - June | | - | - | - | - | - | - | - | - | - | | | |
| - July | | - | - | - | - | - | - | | - | - | - | - | - |
| Precipitation DFN[1)] - July | - | | | | | | | | | | | | |
| - August | | | | | + | | | | | | | | |
| Cumulative precipitation - Sept./April | + | | | | | | | | | | | | |
| - Sept./May | | | | | | | + | + | | | | | |
| - Oct./March | | | | | | | | | | | | | - |
| Cumulative precipitation DFN[1)] squared- -Sept./June | | | | | | | | | | | - | | |
| -Sept./August | | - | - | | | | | | | | | - | |
| **Agroclimatic Variables** | | | | | | | | | | | | | |
| ET[2)]/Climatically Appropriate ET[2)] - May | | | | + | | | | | | | | | |
| - June | | | | | + | | | + | | + | | | |
| - Aug. | | | | | | | | | + | | | | |
| Precipitation-PET[3)] -May | + | | | | | | | | | | | | |
| -June | + | | | | | | | | | | | | |
| Precipitation/PET[3)] -May | | | | | | | | | | | | | - |
| -June | | | | | | | + | | | | | | |
| -July | + | | | | | | | | | | | | |
| -Aug. | | | | | - | | | | | | | | |

1) DFN=Deviation from Normal
2) ET = Evapotranspiration
3) PET = Potential Evapotranspiration

APPENDIX

Brief Description of Growing Conditions for Spring Wheat in Bootstrap Test Years

| Year | North Dakota | Minnesota |
|---|---|---|
| 1970 | Yield down 21%-production down 25%. Lowest yield since 1967, production since 1966.<br>Wet early spring-planting delayed.<br>Central and West areas dry out in July-moisture stress and slow growth.<br>Nitrogen rate/acre up 3½%. | Yield down 8%-lowest yield and production since 1966.<br>Cold, wet spring-planting delayed.<br>Cold and moisture high through June-hot July hurts crop.<br>Leaf rust loss 1.9 bu/acre (all wheat).<br>Nitrogen rate/acre up 12%.<br>Dominant variety is Chris. Era released as new variety. |
| 1971 | Yield up 34½%-production up 87%.<br>Record yield and production-highest harvested area since 1953.<br>Early planting.<br>Moisture and temperature adequate through July.<br>Early harvest after fine growing conditions.<br>Nitrogen rate/acre up 23%. | Yield up 38%-harvested area up 87%.<br>Record yield, harvested area and production.<br>Early planting.<br>Moisture good through July; cold July. Moisture short by mid August.<br>Excellent harvest conditions.<br>Nitrogen rate/acre down 35%. |
| 1972 | Yield down 9½%-production down 26%.<br>Wet early spring-planting delayed.<br>Dry June-mid July, especially Eastern two-thirds of state.<br>Harvest on normal schedule.<br>Nitrogen rate/acre up 2%. | Yield down 13%.<br>Wet spring-planting delayed.<br>Moisture short in North by mid July.<br>Heavy rains/flood in Central during July.<br>Cold wet August delays harvest.<br>Nitrogen rate/acre up 243%. |
| 1973 | Yield down 4½%-production up 11½%.<br>Dry spring-early planting.<br>Much rain in June-early July but South remains dry.<br>Harvest early.<br>Nitrogen rate/acre up 24%. | Yield up 18%-record yield, harvested area and production. Harvested area up 236% from 1970.<br>Cool, dry spring-early planting.<br>Moisture very good through June.<br>July drier.<br>Harvest normal.<br>Nitrogen rate/acre down 7%.<br>Era accounts for 41% and Chris 12% of area. |

APPENDIX

Brief Description of Growing Conditions for Spring Wheat in Bootstrap Test Years

| Year | North Dakota | Minnesota |
|---|---|---|
| 1974 | Yield down 22%-lowest since 1961.<br>Production down 13%-lowest since 1970.<br>Largest harvested area since 1951.<br>Excess spring moisture-late planting.<br>Late June-July very dry (1/3 normal precipitation) and hot.<br>Harvest late.<br>Nitrogen rate/acre down 8%.<br>Dominant variety is Waldon (52%). Olef introduced with 4.2% of area. | Yield down 26%-lowest since 1970.<br>Record harvested area and production. Harvested area up 328% from 1970.<br>Cool wet spring-planting delayed in North.<br>Hail and heavy rains in Central.<br>Hot, dry July.<br>Nitrogen rate/acre down 3%.<br>Era accounts for 65% and Chris 6% of area.<br>Price paid for wheat up 226%. |
| 1975 | Yield up 27½%-production up 26%.<br>Late, wet spring-planting delayed.<br>Heavy June rains-flooding in South Red River Valley.<br>Hot, dry July.<br>Nitrogen rate/acre up 19%.<br>Olef accounts for 18% of planted area. | Yield up 7%.<br>Record harvested area and production.<br>Cold, rainy spring-planting delayed.<br>Hot, dry July and August.<br>Nitrogen rate/acre up 4%. |
| 1976 | Yield down 5%.<br>Record harvested area.<br>Moisture favorable at planting.<br>Hot, dry through August.<br>Early harvest.<br>Nitrogen rate/acre up 29%. | Yield up 5%-harvested area up 41% from 1975 and 470% from 1970.<br>Record production and harvested area. Planting 2-3 weeks early-warmer, drier than normal.<br>Very dry in South and Central during summer, but adequate rain in Red River Valley.<br>Nitrogen rate/acre up 14%. |
| 1977 | Yield up 1%-production down 20%.<br>Low spring moisture.<br>Drought in South and Central.<br>Hot temperature and dry winds in late July-September.<br>Early harvest-heavy rains cause sprouting damage.<br>Nitrogen rate/acre up 2%. | Yield up 23%-record yield and production.<br>Early planting and sprouting.<br>Moisture, temperature adequate through summer.<br>Harvest normal to slightly late.<br>Nitrogen rate/acre up 2%. |

## APPENDIX

### Brief Description of Growing Conditions for Spring Wheat in Bootstrap Test Years

| Year | North Dakota | Minnesota |
|---|---|---|
| 1978 | Yield up 20%-highest yield since 1971.<br>Production up 24%.<br>Very good growing conditions.<br>Frequent rains early in season.<br>Hot, dry mid July-September.<br>Harvest early.<br>Nitrogen rate/acre up 1½%.<br>Olaf accounts for 35% and Waldron 28% of area. | Yield down 16%-production down 31%.<br>Lowest harvested area since 1973.<br>Good early season weather.<br>Heavy rain, wind in early summer.<br>Harvest slowed by wet weather-much lodging occurs.<br>Nitrogen rate/acre up 7%. |
| 1979 | Yield down 12%-production down 11½%.<br>Cold wet spring-planting delayed.<br>Hot dry mid-June.<br>Cool August with heavy rains and lodging in the East, hail damage in East and Central.<br>Premature frost in Northwest (mid-August).<br>Nitrogen rate/acre up 24%. | Yield up 4½%.<br>Lowest production since 1975.<br>Spring planting and development 2 weeks late.<br>Good growing conditions throughout season.<br>Normal precipitation in Red River area.<br>Nitrogen rate/acre up 7%. |

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

| STATE | CRD | YEAR | YIELD (Q/H) ACTUAL | PRED. | D | RD | S.E. PRED. |
|---|---|---|---|---|---|---|---|
| N.DAKOTA | 10 | 1970 | 16.2 | 17.0 | 0.8 | 4.9 | 2.81 |
| | | 1971 | 20.0 | 20.6 | 0.6 | 3.0 | 2.67 |
| | | 1972 | 19.9 | 24.5 | 4.6 | 23.1 | 2.93 |
| | | 1973 | 20.1 | 16.7 | -3.4 | -16.9 | 2.58 |
| | | 1974 | 14.8 | 15.8 | 1.0 | 6.8 | 2.81 |
| | | 1975 | 16.7 | 17.5 | 0.8 | 4.8 | 2.66 |
| | | 1976 | 17.6 | 17.6 | 0.0 | 0.0 | 2.76 |
| | | 1977 | 16.5 | 14.5 | -2.0 | -12.1 | 2.64 |
| | | 1978 | 21.9 | 20.4 | -1.5 | -6.8 | 2.47 |
| | | 1979 | 14.5 | 15.7 | 1.2 | 8.3 | 2.49 |
| | 20 | 1970 | 14.9 | 16.9 | 2.0 | 13.4 | 2.36 |
| | | 1971 | 20.7 | 19.4 | -1.3 | -6.3 | 2.27 |
| | | 1972 | 19.2 | 19.2 | 0.0 | 0.0 | 2.26 |
| | | 1973 | 19.8 | 19.2 | -0.6 | -3.0 | 2.14 |
| | | 1974 | 12.9 | 15.6 | 2.7 | 20.9 | 2.14 |
| | | 1975 | 16.4 | 16.1 | -0.3 | -1.8 | 2.18 |
| | | 1976 | 16.4 | 18.0 | 1.6 | 9.8 | 2.09 |
| | | 1977 | 14.8 | 16.5 | 1.7 | 11.5 | 2.06 |
| | | 1978 | 19.7 | 18.3 | -1.4 | -7.1 | 2.05 |
| | | 1979 | 16.6 | 17.3 | 0.7 | 4.2 | 2.04 |
| | 30 | 1970 | 18.9 | 18.7 | -0.2 | -1.1 | 2.72 |
| | | 1971 | 24.1 | 23.0 | -1.1 | -4.5 | 2.64 |
| | | 1972 | 21.0 | 22.8 | 1.8 | 8.6 | 2.52 |
| | | 1973 | 20.4 | 21.5 | 1.1 | 5.4 | 2.43 |
| | | 1974 | 15.3 | 18.0 | 2.7 | 17.6 | 2.52 |
| | | 1975 | 20.9 | 19.1 | -1.8 | -8.6 | 2.46 |
| | | 1976 | 19.9 | 20.0 | 0.1 | 0.5 | 2.39 |
| | | 1977 | 20.3 | 20.5 | 0.2 | 1.0 | 2.34 |
| | | 1978 | 22.3 | 21.4 | -0.9 | -4.0 | 2.31 |
| | | 1979 | 23.8 | 20.8 | -3.0 | -12.6 | 2.28 |
| | 40 | 1970 | 14.2 | 14.6 | 0.4 | 2.8 | 2.62 |
| | | 1971 | 18.6 | 16.6 | -2.0 | -10.8 | 2.57 |
| | | 1972 | 20.2 | 20.7 | 0.5 | 2.5 | 2.70 |
| | | 1973 | 17.7 | 16.7 | -1.0 | -5.6 | 2.40 |
| | | 1974 | 11.6 | 12.8 | 1.2 | 10.3 | 2.50 |
| | | 1975 | 16.5 | 16.1 | -0.4 | -2.4 | 2.37 |
| | | 1976 | 17.3 | 15.4 | -1.9 | -11.0 | 2.31 |
| | | 1977 | 15.4 | 16.9 | 1.5 | 9.7 | 2.48 |
| | | 1978 | 20.1 | 19.8 | -0.3 | -1.5 | 2.32 |
| | | 1979 | 15.2 | 14.4 | -0.8 | -5.3 | 2.26 |

## APPENDIX
## BOOTSTRAP TEST RESULTS FOR SPRING WHEAT YIELDS IN NORTH DAKOTA AND MINNESOTA USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

| STATE | CRD | YEAR | YIELD (Q/H) ACTUAL | PRED. | D | RD | S.E. PRED. |
|---|---|---|---|---|---|---|---|
| N.DAKOTA | 50 | 1970 | 15.9 | 13.0 | -2.9 | -18.2 | 2.36 |
| | | 1971 | 22.5 | 18.1 | -4.4 | -19.6 | 2.34 |
| | | 1972 | 18.2 | 19.8 | 1.6 | 8.8 | 2.58 |
| | | 1973 | 15.0 | 17.4 | 2.4 | 16.0 | 2.36 |
| | | 1974 | 12.0 | 14.5 | 2.5 | 20.8 | 2.47 |
| | | 1975 | 17.1 | 15.8 | -1.3 | -7.6 | 2.35 |
| | | 1976 | 14.7 | 15.5 | 0.8 | 5.4 | 2.26 |
| | | 1977 | 14.4 | 10.9 | -3.5 | -24.3 | 2.75 |
| | | 1978 | 19.2 | 17.5 | -1.7 | -8.9 | 2.21 |
| | | 1979 | 17.9 | 16.6 | -1.3 | -7.3 | 2.22 |
| | 60 | 1970 | 18.0 | 17.9 | -0.1 | -0.6 | 2.58 |
| | | 1971 | 24.5 | 22.2 | -2.3 | -9.4 | 2.52 |
| | | 1972 | 20.6 | 22.0 | 1.4 | 6.8 | 2.44 |
| | | 1973 | 20.2 | 20.7 | 0.5 | 2.5 | 2.37 |
| | | 1974 | 15.7 | 18.2 | 2.5 | 15.9 | 2.41 |
| | | 1975 | 19.4 | 18.3 | -1.1 | -5.7 | 2.37 |
| | | 1976 | 19.3 | 19.0 | -0.3 | -1.6 | 2.32 |
| | | 1977 | 20.6 | 19.2 | -1.4 | -6.8 | 2.28 |
| | | 1978 | 22.8 | 20.6 | -2.2 | -9.6 | 2.25 |
| | | 1979 | 22.6 | 20.3 | -2.3 | -10.2 | 2.24 |
| | 70 | 1970 | 13.8 | 14.5 | 0.7 | 5.1 | 2.32 |
| | | 1971 | 18.6 | 16.8 | -1.8 | -9.7 | 2.22 |
| | | 1972 | 18.7 | 20.0 | 1.3 | 7.0 | 2.46 |
| | | 1973 | 19.1 | 15.2 | -3.9 | -20.4 | 2.08 |
| | | 1974 | 15.2 | 13.7 | -1.5 | -9.9 | 2.28 |
| | | 1975 | 15.4 | 16.6 | 1.2 | 7.8 | 2.19 |
| | | 1976 | 16.8 | 14.1 | -2.7 | -16.1 | 2.11 |
| | | 1977 | 14.1 | 13.3 | -0.8 | -5.7 | 2.14 |
| | | 1978 | 17.8 | 19.1 | 1.3 | 7.3 | 2.26 |
| | | 1979 | 14.1 | 13.9 | -0.2 | -1.4 | 2.09 |
| | 80 | 1970 | 11.1 | 14.4 | 3.3 | 29.7 | 2.30 |
| | | 1971 | 17.8 | 14.1 | -3.7 | -20.8 | 2.27 |
| | | 1972 | 16.0 | 17.8 | 1.8 | 11.2 | 2.48 |
| | | 1973 | 13.2 | 11.8 | -1.4 | -10.6 | 2.33 |
| | | 1974 | 8.7 | 14.7 | 6.0 | 69.0 | 2.43 |
| | | 1975 | 14.2 | 16.1 | 1.9 | 13.4 | 2.38 |
| | | 1976 | 11.1 | 11.9 | 0.8 | 7.2 | 2.38 |
| | | 1977 | 11.0 | 10.8 | -0.2 | -1.8 | 2.37 |
| | | 1978 | 15.6 | 18.6 | 3.0 | 19.2 | 2.55 |
| | | 1979 | 12.2 | 11.3 | -0.9 | -7.4 | 2.31 |

## APPENDIX
## BOOTSTRAP TEST RESULTS FOR SPRING WHEAT YIELDS IN NORTH DAKOTA AND MINNESOTA USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

| STATE | CRD | YEAR | YIELD (Q/H) ACTUAL | PRED. | D | RD | S.E. PRED. |
|---|---|---|---|---|---|---|---|
| N.DAKOTA | 90 | 1970 | 14.3 | 13.0 | -1.3 | -9.1 | 2.79 |
| | | 1971 | 21.5 | 18.5 | -3.0 | -14.0 | 2.51 |
| | | 1972 | 17.3 | 21.7 | 4.4 | 25.4 | 2.31 |
| | | 1973 | 15.9 | 17.7 | 1.8 | 11.3 | 2.28 |
| | | 1974 | 12.9 | 17.7 | 4.8 | 37.2 | 2.30 |
| | | 1975 | 15.3 | 16.1 | 0.8 | 5.2 | 2.19 |
| | | 1976 | 11.9 | 14.1 | 2.2 | 18.5 | 2.07 |
| | | 1977 | 17.1 | 16.0 | -1.1 | -6.4 | 2.02 |
| | | 1978 | 17.3 | 17.8 | 0.5 | 2.9 | 1.98 |
| | | 1979 | 17.3 | 17.4 | 0.1 | 0.6 | 1.92 |
| STATE MODEL | | 1970 | 15.8 | 15.8 | 0.0 | 0.0 | 2.31 |
| | | 1971 | 21.4 | 19.4 | -2.0 | -9.3 | 2.23 |
| | | 1972 | 19.4 | 19.1 | -0.3 | -1.5 | 2.20 |
| | | 1973 | 18.5 | 17.2 | -1.3 | -7.0 | 2.12 |
| | | 1974 | 13.7 | 15.7 | 2.0 | 14.6 | 2.12 |
| | | 1975 | 17.4 | 16.7 | -0.7 | -4.0 | 2.14 |
| | | 1976 | 16.6 | 16.8 | 0.2 | 1.2 | 2.04 |
| | | 1977 | 16.7 | 15.5 | -1.2 | -7.2 | 2.07 |
| | | 1978 | 20.1 | 18.1 | -2.0 | -10.0 | 1.97 |
| | | 1979 | 17.7 | 17.2 | -0.5 | -2.8 | 1.97 |
| CRDS AGGR. | | 1970 | 15.8 | 16.1 | 0.3 | 1.9 | |
| | | 1971 | 21.4 | 19.6 | -1.8 | -8.4 | |
| | | 1972 | 19.4 | 21.5 | 2.1 | 10.8 | |
| | | 1973 | 18.5 | 18.1 | -0.4 | -2.2 | |
| | | 1974 | 13.7 | 16.1 | 2.4 | 17.5 | |
| | | 1975 | 17.4 | 17.1 | -0.3 | -1.7 | |
| | | 1976 | 16.6 | 16.8 | 0.2 | 1.2 | |
| | | 1977 | 16.7 | 16.0 | -0.7 | -4.2 | |
| | | 1978 | 20.1 | 19.5 | -0.6 | -3.0 | |
| | | 1979 | 17.7 | 16.9 | -0.8 | -4.5 | |

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

| STATE | CRD | YEAR | YIELD (Q/H) ACTUAL | PRED. | D | RD | S.E. PRED. |
|---|---|---|---|---|---|---|---|
| MINNESOTA | 10 | 1970 | 18.5 | 19.9 | 1.4 | 7.6 | 2.27 |
| | | 1971 | 26.9 | 26.2 | -0.7 | -2.6 | 2.26 |
| | | 1972 | 24.2 | 25.7 | 1.5 | 6.2 | 2.14 |
| | | 1973 | 26.0 | 24.6 | -1.4 | -5.4 | 2.09 |
| | | 1974 | 18.6 | 20.7 | 2.1 | 11.3 | 2.23 |
| | | 1975 | 22.7 | 23.2 | 0.5 | 2.2 | 2.15 |
| | | 1976 | 24.6 | 25.6 | 1.0 | 4.1 | 2.04 |
| | | 1977 | 23.6 | 24.4 | 0.8 | 3.4 | 2.01 |
| | | 1978 | 26.6 | 27.1 | 0.5 | 1.9 | 1.97 |
| | | 1979 | 24.9 | 26.5 | 1.6 | 6.4 | 1.94 |
| | 40 | 1970 | 18.4 | 20.0 | 1.6 | 8.7 | 2.75 |
| | | 1971 | 23.3 | 22.9 | -0.4 | -1.7 | 2.74 |
| | | 1972 | 17.3 | 21.4 | 4.1 | 23.7 | 2.88 |
| | | 1973 | 26.7 | 22.2 | -4.5 | -16.9 | 2.62 |
| | | 1974 | 19.4 | 22.2 | 2.8 | 14.4 | 2.86 |
| | | 1975 | 18.2 | 22.3 | 4.1 | 22.5 | 2.77 |
| | | 1976 | 14.9 | 19.3 | 4.4 | 29.5 | 3.09 |
| | | 1977 | 28.6 | 23.1 | -5.5 | -19.2 | 2.77 |
| | | 1978 | 17.3 | 24.5 | 7.2 | 41.6 | 2.82 |
| | | 1979 | 21.6 | 24.6 | 3.0 | 13.9 | 3.00 |
| STATE MODEL | | 1970 | 18.6 | 19.2 | 0.6 | 3.2 | 2.20 |
| | | 1971 | 25.6 | 24.2 | -1.4 | -5.5 | 2.17 |
| | | 1972 | 22.2 | 22.9 | 0.7 | 3.2 | 2.20 |
| | | 1973 | 26.2 | 24.5 | -1.7 | -6.5 | 1.98 |
| | | 1974 | 19.5 | 20.9 | 1.4 | 7.2 | 2.14 |
| | | 1975 | 20.9 | 22.0 | 1.1 | 5.3 | 2.00 |
| | | 1976 | 21.8 | 24.4 | 2.6 | 11.9 | 1.94 |
| | | 1977 | 26.8 | 24.4 | -2.4 | -9.0 | 1.94 |
| | | 1978 | 22.7 | 25.8 | 3.1 | 13.7 | 1.94 |
| | | 1979 | 23.6 | 25.5 | 1.9 | 8.1 | 1.95 |
| CRDS AGGR. | | 1970 | 18.5 | 19.9 | 1.4 | 7.6 | |
| | | 1971 | 25.9 | 25.3 | -0.6 | -2.3 | |
| | | 1972 | 22.3 | 24.5 | 2.2 | 9.9 | |
| | | 1973 | 26.3 | 23.8 | -2.5 | -9.5 | |
| | | 1974 | 18.9 | 21.3 | 2.4 | 12.7 | |
| | | 1975 | 20.9 | 22.9 | 2.0 | 9.6 | |
| | | 1976 | 20.9 | 23.2 | 2.3 | 11.0 | |
| | | 1977 | 25.5 | 23.9 | -1.6 | -6.3 | |
| | | 1978 | 23.3 | 26.2 | 2.9 | 12.4 | |
| | | 1979 | 23.8 | 25.9 | 2.1 | 8.8 | |

APPENDIX
BOOTSTRAP TEST RESULTS
FOR SPRING WHEAT YIELDS IN
NORTH DAKOTA AND MINNESOTA
USING A CEAS TREND AND MONTHLY WEATHER DATA MODEL

| STATE | CRD | YEAR | YIELD (Q/H) ACTUAL | PRED. | D | RD | S.E. PRED. |
|---|---|---|---|---|---|---|---|
| REGION CRDS | AGGR. | 1970 | 16.1 | 16.5 | 0.4 | 2.5 | |
| | | 1971 | 22.0 | 20.4 | -1.6 | -7.3 | |
| | | 1972 | 19.9 | 22.0 | 2.1 | 10.6 | |
| | | 1973 | 19.9 | 19.1 | -0.8 | -4.0 | |
| | | 1974 | 14.7 | 17.1 | 2.4 | 16.3 | |
| | | 1975 | 18.1 | 18.2 | 0.1 | 0.5 | |
| | | 1976 | 17.5 | 18.2 | 0.7 | 4.0 | |
| | | 1977 | 18.7 | 17.8 | -0.9 | -4.8 | |
| | | 1978 | 20.7 | 20.8 | 0.1 | 0.5 | |
| | | 1979 | 18.9 | 18.7 | -0.2 | -1.1 | |
| STATES | AGGR. | 1970 | 16.2 | 16.2 | 0.0 | 0.0 | |
| | | 1971 | 22.0 | 20.1 | -1.9 | -8.6 | |
| | | 1972 | 19.9 | 19.7 | -0.2 | -1.0 | |
| | | 1973 | 19.9 | 18.6 | -1.3 | -6.5 | |
| | | 1974 | 14.9 | 16.8 | 1.9 | 12.8 | |
| | | 1975 | 18.2 | 17.8 | -0.4 | -2.2 | |
| | | 1976 | 17.9 | 18.7 | 0.8 | 4.5 | |
| | | 1977 | 19.3 | 17.8 | -1.5 | -7.8 | |
| | | 1978 | 20.7 | 19.8 | -0.9 | -4.3 | |
| | | 1979 | 18.9 | 18.9 | 0.0 | 0.0 | |



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